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SPECTROSCOPIC RESULTS OBTAINED AT THE SOLAR ECLIPSE OF MAY 28, 1900.

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THE participation of an expedition from the Yerkes Observatory in observing the eclipse was for some months doubtful. On account of the lack of funds for the purpose, it seemed in the preceding winter that it would be impossible to equip and send out a party from the Observatory. In the early spring, however, the chances of financial assistance had improved so that preparations began to be made in the first weeks of April.

In the original plan for the spectroscopic observations it was intended that the principal instrument should be a slit spectrograph, on account of the desirability of securing a metallic comparison spectrum adjacent to the eclipse spectrum, and because of the possibility of bringing a slit spectroscope into perfect adjustment by observations on the Sun previous to the day of the eclipse. As attention was chiefly to be given to the flash spectrum, the plan was considered of selecting for the work a station separate from the rest of the party and near the boundary of the shadow, where the phenomena of the flash at second and third contacts would proceed slowly as compared with the

conditions on the central line of totality. This separation of the party would make necessary an increased amount of apparatus, however, particularly a telescope mounting or another coelostat, and it soon became evident that this could not be procured in the time remaining. As the work of fitting out the instruments for the expedition advanced in the shops of the Observatory, under the efficient supervision of Mr. Ritchey, it further became clear that it would not be possible to construct a suitable mounting for the slit spectrograph, hitherto employed in connection with the 40-inch refractor for stellar work, in the interval remaining before it would be necessary to despatch a freight car with the equipment of the whole expedition. Accordingly, at the end of April, the writer submitted to the Director a plan substituting several objective-prism and objective-grating spectroscopes for the slit spectrograph, and this plan was adopted. These slitless spectroscopes offer decided advantages in their simplicity of construction and mounting, and moreover give the spectrum of a considerable portion of the Sun's limb instead of the small section included within the slit. Furthermore, successful results are much less dependent upon exactly the right instant of exposure than is the case with instruments provided with slits. The fortnight remaining before the necessary shipment of the freight car was fully occupied with the selection and preparation of the prisms, gratings, and objectives, and the supervision of the construction by the carpenters of the wooden mountings for these instruments.

GENERAL ARRANGEMENTS.

A plane silvered mirror of 15 inches aperture had been ordered from Mr. O. L. Petitdidier, and was to be attached to the coelostat mounting which also carried a 12-inch plane mirror furnishing the beam for Professor Barnard's 6-inch long-focus lens. A second silvered mirror of 14 inches aperture, kindly loaned by Mr. Petitdidier, received the beam from the 15-inch coelostat mirror and deflected it northward horizontally at a height of about three feet from the ground. Thus the danger of interference between the 62-foot square tube for the

coronal pictures and the spectroscopic instruments was entirely avoided.

Four square posts about 7×7 inches and 4 feet high were planted at the corners of a rectangle 6 feet long by 3 feet wide so that the beam should pass between the two pairs of posts 3 feet apart. Crosspieces were nailed to the posts so that the instruments could be set up in a plane making an angle of 38° with the horizontal, the west end being the elevated one. The position angles of second and third contact were calculated for our station by Professor Flint, using the determination of latitude and longitude just made by the United States Coast and Geodetic Survey, as 68° 34′ and 264° 16′ from the north point, or 130° 27′ and 326° 10′ from the vertex, differing slightly from the computation previously made by the writer with the coördinates of Wadesboro taken from a map. Inasmuch as these points of contact were 164° apart, the direction of the edges of the prisms or rulings of the grating could not be tangential to the point of contact unless the whole plane of support of the spectroscopes was rotated through 16° between second and third contacts. As this would have greatly jeopardized the stability of the wooden mounting, the writer early decided to make the mounting rigid and let the plane of the instruments make an angle of 8° with the point of each contact.

Inasmuch as a nearly circular beam of light of about 100 square inches section could thus be obtained, it was evidently possible to employ a number of spectroscopes, and the essential parts of six such instruments were taken by the writer for the purpose. Two of these were not used at the eclipse on account of the crowding of the various other spectroscopes into the beam, and on account of the lack of time for their satisfactory adjustment after our arrival at Wadesboro on May 17.

SPECTROSCOPIC OUTFIT.

The following instruments were employed for obtaining the spectrum of the chromosphere and corona:

1. A train of three large prisms intended for the new spectrograph for determining stellar motions in the line of sight now in

the process of construction. These prisms are of unusually white flint glass, and have for the ray λ 4227, for which they were set at minimum, an index $n = 1.6418$. Their height is 2.25 inches (57 mm), and their faces increase in size, being respectively 117 mm, 127, and 135 mm long. The angles of the prisms are 66° 1′, and the total deviation for λ 4227 was 182° 30′. The mean path of the rays in the glass was 206 mm (8 inches), and the theoretical resolving power of the train for λ 4227 was consequently about 107,000.

The prisms were set at minimum deviation for λ 4227 on account of the blue coronal line at λ 4231 which it was hoped could be photographed during totality. No attention was given to the extreme violet region, as it was known that other parties (particularly that from Johns Hopkins University) would be especially well equipped for work in that region, and similarly for the green portion of the spectrum, near the chief coronal line at λ 5303, which was to receive particular attention from the observers from Princeton.

The prisms were mounted in a wooden box 19 × 13 inches in size and 3 inches high, provided with two apertures, one rectangular, 2⅛ inches high and 2½ inches wide, to receive a portion of the beam from the coelostat, and the other circular, of 3½ inches diameter, to receive the lens end of the camera tube. The camera tube, objective and plate-holder were taken from the solar spectroscope of the 40-inch refractor. The objective has an aperture of 3¼ inches, and a focal length of 42 inches, and is corrected for the photographic rays. The plate-holder is movable in a vertical direction so that several exposures may be made on the same plate. The length of spectrum admitted to the plate by this plate-holder is only 75 mm (3 inches), which was unfortunate, as a fairly good focus might have been obtained from the lens over a longer extent of spectrum.

The focal setting of the camera was determined by photographs of star trails at the Yerkes Observatory, and a series of solar spectra of very good definition were obtained at Wadesboro by the use of a collimator of the same size as the camera

lens and the slit of the solar spectroscope. Probably the best method of focusing a prismatic camera is by photographing the spectra of bright stars, as Sir Norman Lockyer has done, but it was not feasible in this case on account of the fixed azimuth of the mounting of the spectroscopes; there were no stars sufficiently bright at the same declination as that of the Sun at the date of the eclipse.

A 3-inch tube of forty inches length was placed in front of the prism box in the path of the beam from the coelostat for the purpose of excluding extraneous light. These tubes and the prism box were firmly attached to a stout board 4 feet in length which was fastened to the crosspieces from the four posts, which formed the basis of the support of all the spectroscopes. The exposures of this prismatic camera were made with a bulb shutter.

2. The instrument second in importance was a small concave grating of 150 cm (59.1 inches) radius, with a surface 44 mm wide and 21 mm high ruled with 14,438 lines to the inch. It was used as a direct grating spectroscope without slit or lenses. Since the object to be observed, the Sun's limb at second and third contacts, was at an "infinite" distance, the focal length of the grating was one half its value with the usual laboratory mounting, or 75 cm. To be in focus for its whole extent the photographic plate should be bent to a radius of one fourth the radius of curvature of the grating, or 37.5 cm. As this was quite impracticable, on account of the danger of breaking the plate as well as from lack of time to construct a proper device for the purpose, a plane plate 4 × 5 in size was used. A simple light-tight box was constructed, of about 6 inches height, 30 inches length, and 18 inches width. The grating was placed in one corner, opposite the aperture of 2 × 2½ inches, and diagonally opposite the grating the plate-holder was held in grooves. Cardboard diaphragms at suitable points within the box protected the plate from stray light. A small brass plate held in place by gravity served as a shutter, and the exposure could be made by drawing a cord. The grating was set in the position perpendicular to

the diffracted beam, to which the plate was also perpendicular. The spectrum of the first order was used, and light of about wave-length λ 4600 fell at the center of the plate.

3. For the visual observation of the flash in order to determine the proper time for making the exposures of the other spectroscopes, a small plane objective-grating was employed. The ruled surface was 2½ × 2 inches, with 14,438 lines per inch. The spectrum of the second order, in the yellow region, was used for the observations. The objective was of 2 inches aperture, and 20 inches focal length. The mounting consisted simply of a square wooden tube, with the grating attached to the prolongation of one of the sides of the tube. The eyepiece gave a power of about 20.

4. A large plane grating, with a ruled surface of five inches and 20,000 lines to the inch, was employed (in the first order) in the hope of photographing the red portion of the flash spectra. The camera lens was a visually corrected objective from the solar spectroscope, of 3¼ inches aperture and 42 inches focus, and was mounted in a wooden tube, with the grating set up on the prolongation of one of its sides. The iris shutter was operated by hand by the writer, while observing at the eyepiece of the visual objective-grating. The photographic "Erythro" plates were kindly given by the International Color Photo Company, of Chicago. These have been successfully used at the Yerkes Observatory for photographing the red end of stellar spectra. In order to cut out the violet of the second order a red glass screen had to be inserted in the tube. It was unfortunately quite thick, and this, with the necessarily short exposure, is responsible for the failure of these plates to give results of value. Four exposures were made, of about 5 and 7 seconds at the time of second and third contacts, of 55 seconds during totality, and of ½ second immediately after totality. The last plate faintly shows a few bright and dark lines, and one of the exposures to the flash has a faint streak of spectrum, but the short exposure time, for which the sensitiveness of the plates could hardly be expected to be sufficient, permitted no traces to be impressed on the other plates.

It is to be regretted that another prismatic camera, having as objective a small photographic doublet of 7 inches focus, with a very transparent prism of 60° angle, was not employed at the eclipse for photographing the coronal rings over a long extent of spectrum. On account of its rapidity this camera might perhaps have yielded results for the green coronal line which was not obtained with the more powerful apparatus of some of the other parties at Wadesboro. As the other instruments kept the two observers sufficiently occupied, and as there was no available time in which to mount and adjust this spectroscope until the morning of the eclipse, it seemed best not to attempt to use it.

It is a pleasure to record the indebtedness of our party, and particularly of the writer, to G. S. Isham, M.D., of Chicago, who spent the week preceding the eclipse with us, and took part in the preparations with great vigor, and supplemented his own scientific and mechanical skill by supplying the means for employing additional carpenters. He sent to Wadesboro the large tent which covered the spectroscopic outfit, into which the beam from the coelostat was reflected.

EXPOSURES AND VISUAL OBSERVATIONS.

The exposures with the prism-train and the concave grating were made by Dr. Isham, while the writer observed visually to give the signal for exposures at second and third contacts, and operated the objective-grating for the red end of the spectrum. Although it had not been possible for us to rehearse our parts until the evening before the eclipse, we were fortunate enough to carry out our program of exposures without mishap. Every fifth second of time, beginning 60 seconds before the computed instant of second contact, was called out to us by Professor A. S. Flint, who also observed the times of contact with a 3-inch equatorial mounted near by.

The visual observations of the flash spectrum, or spectrum of the reversing layer at the instant of second and third contacts, did not correspond to the writer's expectations of the appearance

of those phenomena. On looking into the eyepiece about a minute before the predicted time of second contact, the dark Fraunhofer lines were appearing, and were quite sharply defined 45 seconds before that contact, as the solar cusp rapidly narrowed down and gave the equivalent of a narrow slit. The bright helium line D_3 appeared as a bright crescent, rendered irregular by several prominences, some ten seconds before totality, and was followed by a succession of other lines, until perhaps 15 or 20 were visible in the rather small field of the eyepiece, when the signal was given to make the exposures for the first flash. The expected reversal of all the dark lines visible in the field was not observed, and the writer cannot believe that the phenomenon took place in the brilliant and striking manner that has been recorded by other observers, in particular by Professor Young, at other eclipses. The experience of other observers of this eclipse seems to be similar to the writer's.

After changing the plate-holder of the objective-grating for the red end of the spectrum, and beginning with it an exposure on the coronal spectrum, there was an opportunity for the naked-eye observation of the corona. The drawing made from photographs with Professor Barnard's smaller cameras, reproduced as Plate I in this volume of this JOURNAL, represented very well the impression received by Dr. Isham and the writer. A brief glance into the visual spectroscope at about the middle of totality did not disclose any coronal rings, although if the eye had been kept at the eyepiece the D_3 line would probably have been visible as a partial ring during a considerable part of totality. The region of the principal coronal line at λ 5303 was not included in the field of view. The plate-holders had been changed in preparation for the second flash after about 75 seconds of the computed 92 seconds of the totality had elapsed, and the writer's eye was placed in position at the visual spectroscope. Shortly after the call of the eightieth second, to the observer's surprise, the chromospheric lines, or crescents, began to appear, and the signal for exposure was given at what was

probably about six or seven seconds before the count for 92. These exposures appear from the plates to have been a trifle late. That third contact occurred several seconds earlier than had been anticipated was also noted by Professor Flint and by others of our party.

The display of the bright lines of the reversing layer was visually no more brilliant than at the first flash, and they were quickly effaced by the streaks of continuous spectrum which appeared as totality ended. The observer's attention now had to be given to changing plate-holders and making a final exposure, about ten seconds after totality, for the combination spectrum of the meniscus of photosphere (dark lines), and the lower chromosphere at the cusp (bright lines). For convenience this is called the cusp spectrum.

GENERAL FEATURES OF THE PLATES.

Except for the red-sensitive plates already mentioned, Cramer's Crown 4 × 5 plates were used. They were backed with the caramel mixture employed by Professor Barnard for the large coronal plates. They were developed by the writer, with the assistance of Mr. Ellerman, soon after our return to the Yerkes Observatory. Aside from the four plates exposed to the red end of the spectrum, on which prolonged development failed to bring out images of sufficient intensity to be of value, the photographs may be regarded as satisfactory. The focus of both prisms and grating spectroscopes would probably have been somewhat sharper if it had been possible to adjust them by stellar spectra. There is in case of the stronger bright lines on most of the plates a curious tendency to shade away from sharpness on the side toward red to fuzziness on the side toward violet. That this is not a result of imperfect focusing appears from the fact that it occurred with both prisms and grating, and operated only in the direction of dispersion, and seems to affect the bright lines, but not the dark lines. It is most marked on the first flash with the prism-train, and least so on the first flash with the grating. It is not unlike the hypothetical appearance

depicted by Sir Norman Lockyer on p. 126 of his *Recent and Coming Eclipses* (1900), to illustrate the possible effect of different distributions of concentric layers of vapors above the photosphere. It cannot be thus explained, however, as that would require the haziness to change from the side toward violet to the side toward red between the first and second flashes. The effect of this haziness toward violet upon the measures of the plates taken at third contact is described later. We may now examine the plates in some detail.

Spectrum of the solar cusp just before and after totality.—These two plates were taken with the prism-train, the first at the call of 15 seconds before second contact, and the second at 10 seconds after third contact, with exposures of about one half second. The spectra of the first flash and of the corona were also included on the same plate with the first of the cusp spectra. A corner of the plate was unfortunately broken off in the dark room, as it was being removed from the plate-holder; it was also necessary to cut the plate during development, in order that the development of the weak coronal plate could be pushed further than that of the other two strong impressions on the plate. The appearance of the plate was thus injured so that a reproduction of it is not given. The measurements of the plate were not seriously affected, however, the two parts being separately measured and reduced. A reproduction of the plate of the cusp after totality, enlarged three times, was given in the July number of this JOURNAL (Plate IX, Fig. 2 of this volume).

These plates show many interesting features. The continuous spectrum on the first has a width of 4 mm, the Sun's diameter being 10 mm, while on the second plate the width of the continuous band is 5 mm. This indicated that the first, exposed at the call of 15 seconds before the completed time of beginning of totality, was actually taken at an instant nearer totality than the second, which was exposed at the estimate of 10 seconds after the plate taken at third contact. This confirms the observations made by others that the contacts occurred some seconds in advance of the computed times.

The continuous spectrum is strong on these plates, and a slightly shorter exposure, say of ¼ second, might perhaps have been better. The continuous spectrum is strongest along the center of the spectrum, diminishing slightly toward the edges, which are, however, rather sharper than might have been expected. At about position-angle 90° there is a very strong break lengthwise in the continuous spectrum, of a width of 0.2 mm, on the first plate. This is presumably produced by a lunar crater of considerable height and of about forty-five miles diameter. The stronger bright lines extend across this gap, indicating that their level was high enough not to be obstructed by the lunar obstacle. The writer has not taken pains to identify this crater. Oddly enough, a number of the dark lines show marked distortion where they resume beyond this gap. On the second cusp spectrum there is also a conspicuous horizontal gap in the spectrum, but the dark lines as well as the bright can be seen to cross it, indicating that the Moon moved enough during the exposure to uncover that portion of the chromosphere, reversing layer and photosphere.

The first plate covers the region of spectrum from λ 4050 to λ 4430; the second that from λ 4025 to λ 4380; the difference is due to the change of 32′ in the incidence of the light, first from the east limb and then from the west limb of the Sun, so that the images are shifted 10 mm on the second plate. All the stronger lines on Rowland's map are shown as dark arcs, in many cases terminating in bright tips at the edge of the continuous spectrum. It is obviously a matter of the highest importance to determine what lines are thus reversed, for upon this turns the question of the existence of a thin stratum of vapors at the base of the chromosphere, called the reversing layer, by the absorptions of which the dark Fraunhofer lines are produced.

It is undeniable that the first impression produced upon the examination of the plates is that there are many marked differences between the bright line and dark line spectrum, and this impression, shared by Professor Hale and the writer, was stated

in the Director's report on the observations at the eclipse (p. 86 of this volume of this JOURNAL). The bright lines most conspicuous on account of their intensity and breadth are not the strongest dark lines; a few of the finer bright lines also extend across the whole band of continuous spectrum and do not seem to merge into any dark line. But a close examination, and still better, the measurements detailed below, show that the case is rather exceptional when a strong dark line does not terminate in a bright one. The most conspicuous bright lines in the region of spectrum here covered are the hydrogen lines $H\gamma$ and $H\delta$, the strontium lines at λ4077.9 and 4215.7, the calcium line at λ4226.9, the line at λ4177.7 (perhaps due to iron), a line of uncertain origin at λ4233.3, the scandium line at λ4320.9, and the chromium line at 4351.9. These have all been long known in the ordinary chromospheric spectrum, and were included in Professor Young's list of lines observed in 1872. Hence it was to be expected that these lines would be conspicuous in the eclipse photographs.

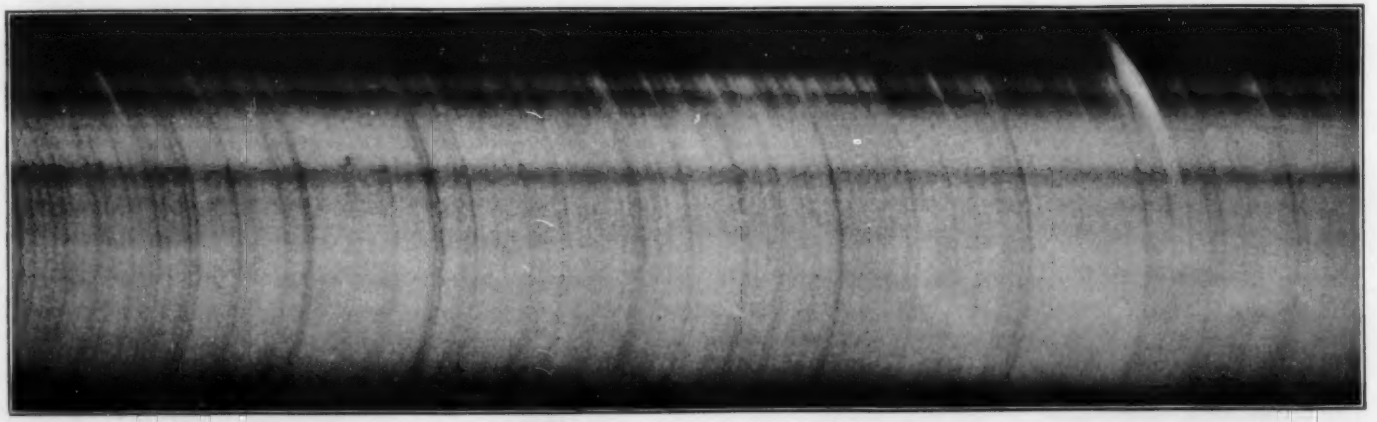
An examination of Plate XXII, which is enlarged eight times from a portion of the original plate of Cusp II, will show quite clearly that very few dark lines can be found, even among the great number in the large group from λ4285 to λ4315, which do not terminate in a bright tip. This is the essential point in the inquiry as to the existence of the reversing layer. We shall return to it in the discussion of the other plates and of the identification of the lines by their wave-lengths.

Many other phenomena of a highly complex nature are indicated upon these plates taken before and after totality. We are evidently dealing with a superposition of spectra. The bright lines which extend across the whole width of the continuous spectrum appear in some instances to be of different curvature than the dark lines. In some cases the dark lines extend into the bright lines with the same arrowhead effect that is often seen with the prominence spectroscope; in other instances the dark lines merge insensibly into the bright ones.

It is of interest to examine these plates for any uniform

PLATE XXII

4272 4308 4340



PORTION OF SPECTRUM TAKEN TEN SECONDS AFTER TOTALITY

EIGHT-FOLD ENLARGEMENT

relative displacement of the bright lines with respect to their dark counterparts. On the first plate there are many instances in which the bright lines fall on the violet side of the dark lines, that is, on the convex side, but there are several exceptions to this. On the second plate, taken after third contact, many of the bright lines also appear to lie toward the violet of the dark lines, here on the concave side, but also with numerous exceptions. The displacement, where evident, would seldom exceed 0.1 tenth-meter in amount. For studying this point, a slit spectrograph, which avoids the disturbing effect of the curvature of the lines, would seem to the writer more suitable, especially if a metallic spectrum with numerous lines is simultaneously recorded on the plate. In view of the inconstancy of this effect of displacement on the plates here described, it does not seem advisable to base any theoretical considerations upon it.

In the case of the very large bright $H\gamma$ line we have an effect similar to a double reversal; for about the central half of the length of the arc the dark line appears, running out in each direction into a point, from a width at the middle of the arc of about one third of the width of the bright arc.

FLASH SPECTRA AT SECOND AND THIRD CONTACTS.

1. *Plates taken with the prism-train.*—These two plates cover the same range as the corresponding cusp plates. The first records no continuous spectrum, and hence no dark lines; the bright lines merely show a thickening at the parallel along which the contact occurred. Possibly the exposure was made a trifle too late. The second plate, at any rate, which received quite a band (1.5 mm wide) of continuous spectrum, shows many more lines. The exposures were intended to be of two seconds each. Dr. Isham's impression was that the exposure at the first flash was perhaps slightly prolonged beyond the two seconds. Eighty bright lines are given in the tables below as measured on the first plate, and 265 on the second. The second plate, enlarged three times, was reproduced in the July number of the ASTROPHYSICAL JOURNAL (Plate IX, Fig. 1, of this volume). The

streak of continuous spectrum on that plate represents an arc of about 17°. At about position angle 263° the continuous spectrum was interrupted, presumably by a lunar crater.

Just beyond the continuous spectrum, at about position angle 255°, there is a very marked distortion of the bright lines, which may be seen on the reproduction (opposite p. 85). It averages about 0.3 tenth-meter, corresponding to a velocity of recession of about 20 km per second.

Dark lines are very inconspicuous on this plate. This note was made during the measurement of the ten bright lines at the extreme end of the plate toward violet: "All seem to be at the violet edges of dark lines." Between λ 4081 and λ 4086 "numerous dark lines" were noted. Measures were made on five dark lines, as follows:

	Fine	Fine	Fine	? Fine	Quite strong
	λ 4143.8	4150.2	4159.1	4159.6	4168.5
Rowland	4143.57 *Fe* 4 4143.66 2	4149.92 2	4158.96 *Fe* 5	4159.35 5	4168.03 2 4168.13 *Ni* 2 4168.78 2

These lines are not conspicuous in the solar spectrum. They evidently originate at a very low level. The roughly uniform difference of wave-length from Rowland's value is a numerical confirmation of the above statement that the bright lines lie at the violet edges of the dark lines.

The solar prominence at position angle 217° is faintly shown on these plates; on the grating plates it is conspicuous, and the other larger prominences at the date are also seen.

2. *Plates taken with concave grating.*—The total range of spectrum included on these plates is from about λ 3700 to λ 5200, but owing to the necessity of using a flat plate the focus is sufficiently good for satisfactory measurement only from λ 4200 to λ 4900, the lines in which region are included in a subsequent table. The H and K lines are very strong and broad, and about twenty lines, chiefly of the hydrogen series, may be seen beyond K toward the violet, terminating with $H\pi$.

The exposures were intended to be of two seconds each, but it was recorded immediately after totality that the first was

PLATE XXIII

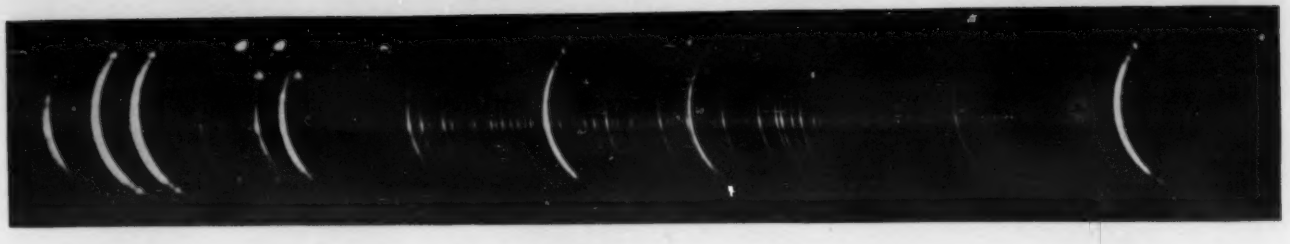


FIG. 1.— FLASH AT SECOND CONTACT

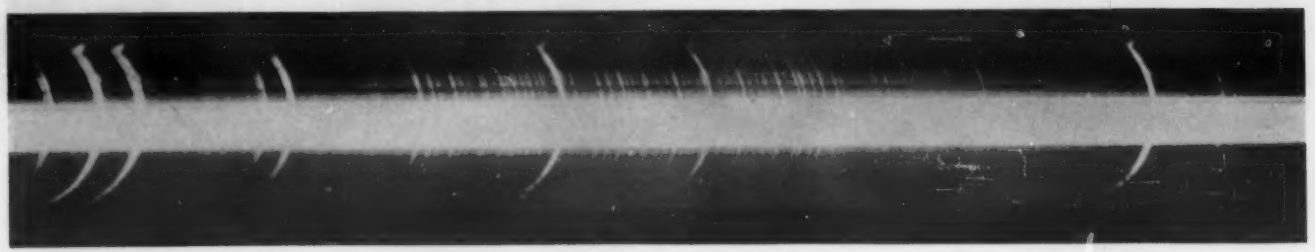


FIG. 2.— FLASH AT THIRD CONTACT

SPECTRA PHOTOGRAPHED WITH CONCAVE GRATING

perhaps underexposed. As will be seen from the reproduction (enlarged 3.4 times), Plate XXIII, Fig. 1, the first plate only received a very slight streak of light, if any, from the photosphere. (In the parts in best focus this band can be almost entirely, if not wholly, resolved into lines.) The second plate (Fig. 2) shows a band indicating that a meniscus of about 25° of photosphere affected the plate before the end of the exposure. A few dark lines appear at the ends of the plate, but not in the central part. Both plates exhibit a broad band of continuous spectrum, slightly greater than the Sun's diameter, which is doubtless due to the inner corona. This band contains certain horizontal streaks of greater intensity, which seem to correspond exactly to those shown on the plate of the corona, of which a figure is given on page 349.

We may obtain an inference as to the height of the strata producing the bright arcs from the measurement of the angular extent of the arcs. The lengths of some of the more conspicuous arcs have accordingly been roughly measured, and are collected in the following table, together with the approximate elevations of the strata deduced from the arcs of the flash spectra. In calculating these values the Sun's semidiameter was taken as 946″.6, and that of the Moon, augmented, as 968″.9.

APPROXIMATE LENGTHS OF CERTAIN BRIGHT ARCS.

Plate	*He* 4471	*H*γ 4340	*Sc* 4321	*Cr* 4274	*Cr* 4254	*Fe* pair 4250	*Y*? 4247	? 4233	*Ca* 4226	*Sr* 4215	*H*δ 4102	*Sr* 4078
Prisms—												
Cusp I		80°						60°	55°	60°	80°	75°
Cusp II		90	55	55		60	65	70	65	70	90	85
Flash I					40	10	45	35	45	60	85	65
Flash II		100	50	45	50	30	55	45	55	65	100	95
Grating—												
Flash I	100	95	45	35	45		55	45	50	60	80	50
Flash II	105	110	45	45	50		55	45	55	70	100	75
Approximate height	8″	8″	3″	2″	3″	<½″	2″	2″	2″	3″	7″	4″

The arcs for the greater number of lines are not longer than those of the iron pair at λ4250, whence we may safely infer that

the elevation of the strata producing most of the bright lines is less than 1″ above the solar photosphere.

MEASUREMENT OF THE PLATES.

The negatives were measured with the Zeiss Comparator, No. 873, principally used by the writer for the measurement of stellar spectra. The instrument has a scale graduated to 0.2 mm, which moves with the plate and may be read by a second microscope and micrometer to one micron (0.001 mm). A magnifying power of 13 was commonly employed in the microscope with which the plate was observed. The length of the spectrum included on the plates taken with the prism-train was 75 mm. On the plates taken with the concave grating the focus was sufficiently good for measurement over about 40 mm. The linear scale of the prism plates was slightly more than four times that of the grating plates for the region between λ4340 and λ4215.

Either two or four settings were made on each line, the line being alternately brought under the micrometer "thread" (a line ruled on the glass reticle extending half way across the field) from the left and from the right. The parallel, or line in the direction of the length of the spectrum along which the settings were made, was so selected that both the short and the long bright lines could be measured, without involving the end of the "thread" or pointer in the streak of continuous spectrum near the center of the two plates of the second flash, and on the two plates of the cusp. There were no such streaks of continuous spectrum on the two plates of the first flash, so that the settings were made on the parallel through the center of the spectrum, or at the solar position angle of the point of second contact, computed to be 68°. The measurements of the second flash (prism plate) were made at about position angle 278°, and on the grating plate at about 269°. The lines in the spectrum of the cusp ten seconds before totality were measured at about 100°, and on the cusp after totality at about position angle 240°.

On account of the peculiar tendency of the crescents to shade off from sharpness on the side toward the red to diffuseness

on the side toward violet, both for plates taken with prisms and with the grating, it became necessary to make the settings on the red side. Thus the settings were made on the convex sides of the crescents on the plates taken at third contact and on the cusp plate following. Hence unless the crescents or lines are all of equal width, a systematic correction has to be applied to the wave-lengths of the lines on those plates, in order that they may not be in error by an amount corresponding to the thickness of the stratum producing the line or crescent. However, as the measures were made along parallels at some distance from the position angle of third contact, most of the crescents run to a point, and the correction therefore depends upon the thickness of the standard lines at the parallel.

The estimates of the intensities of the lines were made as the lines were measured, and are of course quite rough. Both the intensity proper, for a given width of line, and the whole width, enter into the estimate, which might perhaps be regarded as the product of intensity and width. The scale is purely arbitrary, a line just fairly visible being recorded as of intensity 10, while for the large hydrogen crescents the estimate runs up to 500. The range of width × intensity is much larger for the chromospheric lines than for the dark lines of the solar spectrum. Despite the difference between this scale of intensity and that of Rowland's table, the comparison of the two is not at all difficult, and an examination of the table will show that the majority of strong lines of the chromosphere are also strong on Rowland's map.

REDUCTION OF THE PLATES.

The measures on the plates obtained with the objective-prism were reduced to wave-lengths by the use of the Cornu-Hartmann formula. There was considerable embarrassment in selecting the three standard lines on which the interpolation formula is based. From the experience of other observers of eclipse spectra it was inferred that it was unsafe to assume the identity of any but a few of the most conspicuous chromospheric lines, especially those of hydrogen. But these lines were very broad

and diffuse toward the violet, involving a considerable correction for the plates of the second flash and second cusp. In spite of this it seemed necessary, however, to adopt as standards lines whose identity was unquestioned, and the choice was made of $H\gamma$ (λ4340.63) and the two very strong strontium lines at λ4215.70 and λ4077.89. On account of its fracture near $H\gamma$ the plate of the first flash had to be reduced in two parts, the strong iron line at λ4325.94 being used with the two strontium lines for standards for the larger part of the plate, while for the end toward red, containing only about a dozen bright lines, the iron lines at λ4383.72 and λ4404.93 and the titanium line at λ4417.88 served as standards. Measures on the other plates confirmed the correctness of the identification of these strong lines of the Fraunhofer spectrum with the bright lines on the plate.

In the case of the plate of the solar cusp taken ten seconds before totality, dark lines had to be used as standards. They were, for the violet side of the plate, λ4071.91, 4132.24, and 4271.93; for the other part of the plate λ4308.02, 4325.94, and 4415.29. By basing the wave-lengths of this plate upon the dark lines as standards, a slight lack of homogeneity is introduced, involving a difference in these wave-lengths of the order of any possible displacement of the bright lines with respect to the dark. But as there appeared to be no differences which would affect the result by more than a very few hundredths of a tenth-meter, these values of the wave-lengths have been given the same weight as the others in taking the final mean.

The numerical value of the correction to be applied to the wave-lengths of Flash II and Cusp II, on account of the fact that the measures were made on the convex instead of the concave side of the crescents, or at the top instead of the base of the strata of which the crescents are the images, was determined from measurement of the thickness of the crescents of the standard lines at the parallel along which the settings were made. From these measures correction curves were drawn, varying from +0.13 to +0.24 tenth-meters for Cusp II, and from +0.17 to +0.25 for Flash II, increasing from the end of the plate of

shorter wave-lengths. These corrections were found to be in good agreement with the values suggested by the systematic differences between the wave-lengths of Flash I and Flash II. In the case of the broadest lines, whose width was a considerable fraction of that of the three standard lines, the amount of the correction was diminished by a quantity depending upon the actual thickness of the line in question as measured on Flash I, on which plate the settings were made on both edges. In the case of the grating plate of the second flash a constant correction of +0.2 tenth-meter was applied.

After the tables had been made out in the form given below, and many of the finer lines had been identified with dark lines of Rowland's tables, new formulae were calculated for the violet ends of the plates of Flash II and Cusp II, narrow lines being used as standards. The wave-lengths thus determined accorded so closely (usually within five hundredths of a tenth-meter) with the "adopted wave-lengths" of the table, that the tables were left unchanged.

On account of the smaller linear dispersion of the plates taken with the concave grating, and on account of the falling off in sharpness of focus on both sides of the center of the plates, due to the necessary use of plane instead of curved plates, a lower degree of accuracy was to be expected in the determination of wave-lengths with the grating than with the prism-train. Accordingly it seemed undesirable to reduce the grating plates by any more elaborate process than by treating each in three sections, through each of which the spectrum was assumed to be normal. Fourteen lines were selected as standards, as follows: λ4215.70 (*Sr*), 4226.90 (*Ca*), 4274.96 (*Cr*), 4289.88 (*Cr*), 4307.90 (*Ca*), 4383.72 (*Fe*), 4471.65 (*He*), (*H*γ was used instead of λ4383 on Flash I), λ4501.44 (*Ti*), 4554.21 (*Ba*), 4563.94 (*Ti*), λ4572.16 (*Ti*), 4713.25 (*He*) and 4861.53 (*H*β). The constants a and b of the linear equation $\lambda = ax + b$ were deduced by least squares for each section. The residuals for the standard lines of the middle section average for Flash I, 0.05 tenth-meters; for Flash II, 0.08. For the outer sections the residuals

are larger, averaging for the section toward violet 0.21, and for the section toward red 0.24. Hence the wave-lengths of the few lines beyond λ4600 (toward the red) may be uncertain by a considerable fraction of one tenth-meter.

DESCRIPTION OF THE TABLES.

The results of the measures are collected in the following tables. The first eight columns contain the wave-lengths as deduced from the measurement of the four plates concerned (before any systematic corrections have been applied) with the intensities of the lines as roughly estimated on a scale as described above. The column entitled "adopted wave-length" represents the mean of the different values, after the systematic corrections had been applied to the measures on the plates of the second flash and second cusp. The last three columns, giving the comparison with the dark line, or Fraunhofer spectrum, are extracted from Rowland's "Table of Solar Spectrum Wave-lengths" published in this JOURNAL, Vols. I to V, except that the wave-length of the helium lines, which are not visible as dark lines in the solar spectrum, are taken from the paper by Runge and Paschen (this JOURNAL, Vol. III, p. 3). In this comparison only the stronger lines from Rowland's table which fall within 0.2 tenth-meter (or usually less), and for which the identification seems tolerably certain, have been given. Many more of the lines could be identified with fainter lines of Rowland's list, but with less certainty as to the identity, and doubtless quite a number of the identifications given above are incorrect, based upon an accidental coincidence of the bright and dark lines.

The letter h signifies that the bright line was hazy or diffuse; v h that the line was very hazy; l that it was a long line or arc; s denotes sharp, and d double. Rowland's scale of intensities runs from 1, a line just clearly visible on his map, to 1000 for the H and K lines. Below 1 the scale of faintness proceeds from 0 to 0000. N indicates that the line is not clearly defined or that it is much weaker than it should be for its breadth. Where two or more elements are given under the column entitled Substance, the solar line is compound.

BRIGHT LINES MEASURED ON SPECTRA

Flash II		Cusp II		Flash I	
λ	I	λ	I	λ	I
		4024.3	6 v h		
	–	4024.8	8		
4026.2	80	4026.1			
4028.1	35 s	4028.2	20		
		4029.5			
4031.5	30	4031.6	15		
4032.8	50				
4034.3	60				
4035.4	60	4035.5			
4040.6	50 s	4040.6	30		
4042.8	60 h	4042.8	8		
		4044.3	8		
4045.7	200	4045.5	h l		
4048.6	40	4048.6			
4053.7	12 s				
4054.8	40	4054.8			
4058.8	25				
4061.0	30 s	4061.0	15		
		4062.4	8		
4063.6	50				
		4066.6	6		
		4067.9	10		
4071.8	60	4071.8	40	4071.7	40 s
4075.8	15				
4077.89	200	4077.89	300	4077.89	200 s
4078.4	15				
4081.2	10	4081.3			
4086.3	15	4086.4	9		
4086.8	30 s	4086.8	17 s		
4090.5	12				
4091.4	4				
4092.4	30 h	4092.4	12		
4096.1	15				
4096.7	6 d				
4098.1	4				
4098.2	5				
4098.6	6				
4102.2	500	4102.1	400	4102.2	400
4103.0	25	4103.0	17		
4104.2	15 s	4104.2	12		
4107.5	40 d ?	4107.6	12 d ?		
4109.5	30 v h	4109.2	20		
		4109.9	10		
4110.6	60 h	4110.6	20 h		
4111.4	20 s	4111.4	10		
4111.8	8				
		4113.8	10		
4114.6	20	4114.5			
4115.4	30 h	4115.4	h		

TAKEN WITH PRISM-TRAIN.

Cusp I		Adopted Wave-length	Comparison with Rowland's Table		
λ	I		λ	Substance	I
		4024.4	4024.25	*Fe*	2
		4024.9	4024.73	*Ti*	3
			4024.88	*Fe*	4
		4026.28	4026.34	*He*	
		4028.28			
		4029.6			
		4031.70			
		4032.9	4032.79	*Fe*	4
		4034.4			
		4035.60			
		4040.75	4040.79	*Fe*	3
		4042.93	4042.74	*Cr, Nd*	0
		4044.4			
		4045.76	4045.98	*Fe*	30
		4048.76			
		4053.9	4053.98	*Fe-Ti*	3
		4054.98	4055.02	*Fe*	3
		4059.0	4058.92	*Fe, Cr*	3
		4061.18	4061.24	*Nd–*	3
		4062.6	4062.60	*Fe*	5
		4063.8	4063.76	*Fe*	20
		4066.8			
		4068.1	4068.14	*Fe-Mn*	6
		4071.88	4071.91	*Fe*	15
		4076.0	4076.10	*Fe*	3
4077.9	150	4077.89	4077.89	*Sr*	8
		4078.6	4078.52	*Fe*	4
			4078.63	*Ti*	3
		4081.43			
		4086.52	4086.47	*Co–*	3 d ?
		4086.99	4086.86	*La*	1
		4090.7			
		4091.6	4091.71	*Fe*	3
		4092.6	4092.43	*Fe*	2
		4096.3	4096.13	*Fe*	3
		4096.9			
		4098.3			
		4098.4	4098.34	*Fe*	5
		4098.8	4098.69	*Ca?*	4
4101.9	300	4102.11	4102.00	*H*	40 N
		4103.20	4103.10	*Si, Mn*	5
		4104.40	4104.29	*Fe*	5
		4107.76	4107.65	*Ce-Fe-Zr*	5
		4109.57	4109.22	*Fe*	3
		4110.1	4109.95	*Fe*	3
		4110.81	4110.69	*Co*	4
		4111.63			
		4112.0	4111.94	*V*	4
		4114.0			
		4114.73	4114.61	*Fe*	4
		4115.58	4115.33	*V*	3

Flash II		Cusp II		Flash I	
λ	I	λ	I	λ	I
4118.8:		4118.6:	h		
4119.4	10 s				
4119.9	7				
		4121.1	3		
4121.4	20	4121.4	15 sl	4120.9	15
4122.8		4122.8	12		
4123.2	18	4123.4	25 sl		
4124.0	8	4124.0	8		
4124.9	h	4124.9	15		
		4125.7	5		
4126.6	8				
4127.7	8	4127.4	h		
4128.1	12	4128.2	h		
4128.8	15	4128.8	6		
4129.6		4129.3	7		
4129.8	30	4129.9	20		
4130.7	15	4130.8	8		
4132.2	h	4131.8	8 d ?	4132.2	10
4132.8	10				
4133.4	6				
4133.9	20	4134.0	6		
4134.8	40	4134.7	20		
4135.5	10	4135.5	5		
4137.1	20	4137.1	3		
4139.0	6	4139.1	2		
4139.6	10				
4140.5	8	4140.8	4		
4142.9	7				
4143.2	7	4143.2	7		
4143.9	15			4143.9	30 h
4146.3	60				
4147.7	7	4147.8	30		
4149.3	40 s	4149.4	18	4149.3	15
4150.0	dark line	4150.0	9		
4151.0	30 s	4150.9	5		
4152.2	80 h	4152.1	12 l		
4154.8	50	4154.6	4		
4156.2	40	4156.3	20 h	4156.2	5
4156.8	15			4156.6	7
4158.1	15				
		4160.4	3		
		4161.3	9	4161.1	d ?
4161.6	80 h	4161.6	5		
		4162.0	5		
4162.6	10	4162.3	5	4162.7	7
				4163.2	
4163.7	50	4163.8	12	4163.7	30
4164.3	12			4164.6	5
				4165.1	6
				4165.8	6

Cusp I		Adopted wave-length	Comparison with Rowland's table		
λ	I		λ	Substance	I
		4118.89	4118.71	*Fe*	5
			4118.93	*Co*	4
		4119.6			
		4120.1			
		4121.3			
		4121.36	4121.48	*Cr-Co*	6 d?
		4123.00			
		4123.50	4123.38	*La*	12
			4123.54	*V*	0
		4124.19			
		4125.10			
		4125.9	4125.78	*Fe*	3
		4126.8	4126.67	*Cr*	2
		4127.72	4127.77	*Fe*	4
		4128.37	4128.25	*V*–	6 d?
		4129.01			
		4129.65	4129.62		2
4129.9	20	4130.01			
		4130.92	4130.80	*Ba*	2
		4132.19	4132.24	*Fe*	10
		4133.0	4133.06	*Fe*	4
		4133.6	4133.76	*Fe*	2
		4134.11	4134.01	*Fe*	3
4134.7	10	4134.86	4134.84	*Fe*	5
		4135.69			
		4137.31	4137.16	*Fe*	6
		4139.25	4139.24		0
		4139.8			
		4140.84			
		4143.1			
		4143.41			
		4143.99	4144.04	*Fe*	15
		4146.5			
		4147.87	4147.84	*Fe*	4
		4149.47	4149.53	*Fe*	4
		4150.2			
		4151.18	4151.13	*Zr, Ti*	1
		4152.35	4152.34	*Fe*	3
		4154.90	4154.67	*Fe*	4
			4154.98	*Fe*	4
4156.2	20	4156.34	4156.39	*Zr*	1
		4156.84	4156.83		1
		4158.3			
		4160.6			
		4161.19	4161.24		2
		4161.81	4161.68		4
		4162.2			
		4162.69	4162.62		1 N
		4163.4			
		4163.86	4163.82	*Ti, Cr*–	4
		4164.55			
		4165.1			
		4165.8	4165.76	*Ce*,–	2

Flash II		Cusp II		Flash I	
λ	I	λ	I	λ	I
		4167.3	4	4167.1	8
				4167.6	4
				4168.2	6
4171.1	20	4171.1	15		
4172.0	80	4172.1	15	4171.9	30
4173.5	50	4173.6		4173.5	35
		4174.8	5		
4175.4	10 h	4175.6	6		
4175.7	10 h				
4176.6	3 d ?	4176.6	7		
4177.6	70	4177.7	40	4177.7	40
4179.0	60	4179.0	15	4178.9	25
4179.5	45	4179.4	12		
4180.9	6	4181.0	9	4180.9	4
4181.8	15	4181.8	15		
4182.2 ?	8	4182.5	10		
		4182.8	8		
		4183.3	6		
4184.1	7	4184.0	7		
4184.3	7	4184.4	8		
4185.0	15	4185.0	12		
4185.3	4	4185.4	4		
		4186.1	5		
4186.6	12	4186.7	10		
4187.2	15	4187.1	15 d ?	4187.0	9
4188.0	20	4187.9	15	4187.7	4
4188.7	10				
4189.5	12	4189.6	8		
4190.1	3	4190.0	6		
4190.6	5	4190.7	6		
		4191.0	5		
4191.6	40	4191.5	15	4191.3	6
				4192.0	5
4193.1	5				
4193.7	3				
4194.8	7	4194.9	5		
4195.2	6				
4196.4	6	4196.6	7		
4198.4	20			4198.7	8
4199.2	20	4199.3	7	4199.1	12
4200.6	25 d				
4202.1	40			4202.1	25
4202.9	18	4202.8	6		
4203.9	15	4204.1	4		
4205.0	35	4205.1	15		
4206.6	10	4206.7	7		
		4207.2			
4209.0	20	4209.1	12	4208.9	8

Cusp I		Adopted Wave-length	Comparison with Rowland's Table		
A	I		A	Substance	I
		4167.31	4167.44		8
		4167.6			
		4168.2			
		4171.30	4171.21	*Ti*,–	4
		4172.15	4172.07	*Ti, Fe*	2
		4173.75	4173.71		3
		4175.0	4175.08	*Fe*	5
		4175.74	4175.81	*Fe*	5
		4175.9			
		4176.80	4176.74	*Fe–Mn*	5
		4177.80	4177.70	*Fe*	3
			4177.77		3
		4179.08	4179.02		3
		4179.69	4179.54	*V*,–	3 d ?
		4181.67	4180.97	*C*	2 N
		4182.02	4181.92	*Fe*	5
		4182.6	4182.55	*Fe*	3
		4183.0			
		4183.5			
		4184.28	4184.16		4
		4184.58	4184.47		2
		4185.19	4185.06	*Fe, Cr*	4
		4185.61			
		4186.3			
		4186.87			
		4187.27	4187.20	*Fe*	6
		4188.04	4187.94	*Fe*	5
			4188.02		3
		4188.9	4188.89		4
		4189.77	4189.72	*C*,–	2
		4190.30	4190.29	*Cr*	0 N
		4190.88	4190.87	*C, Co*	1 N d ?
		4191.2			
		4191.68	4191.60	*Fe*	6
		4192.0			
		4193.3			
		4193.9	4193.96	*C*	0
		4195.07	4195.01	*Cr*	1
4195.7	12	4195.60	4195.49	*Fe*	5
			4195.68		1
		4196.73	4196.70	*La*	2
		4198.66	4198.56	3 lines, 2 *Fe*	4, 4, 3
		4199.35	4199.27	*Zr–Fe*	5
		4200.8	4200.61	*Ni*	1
			4200.76		1
		4202.22	4202.20	*Fe*	8
		4203.06			
		4204.01	4204.10	*Fe*	3
4205.1	20	4205.23	4205.24		1
4206.9	15	4206.88			
		4207.4			
		4209.14	4209.14	*Zr*	1

Flash II		Cusp II		Flash I	
λ	I	λ	I	λ	I
4210.4	30				
4211.9	25	4211.8	12		
4213.7	15	4213.6	7		
4214.9	12				
4215.7	100	4215.7	40	4215.7	
4217.5	v h	4217.2	6		
		4217.6	7		
4218.5	6			4218.4	5
4219.3	18	4219.4	12		
4220.3	12	4220.3	15		
4221.4	6				
4222.5	v h	4222.5	group		
		4223 0	6		
4224.0	5				
4224.3	6	4224.2	6		
4225.2	6	4225.4	15		
4226.8	100	4226.8	50	4226.8	100
4227.4	20	4227.4	15		
4230.9	8	4231.1	8		
		4232.4	4		
4233.2	90	4233.2	40	4233.2	30
4233.5	5	4233.6	5		
4235.2	12	4235.2	10	4235.3	8
4236.0	40	4235.9	12	4236.0	9
		4237.2	4		
		4237.9	8		
4238.6	8	4238.4	5		
		4238.8	9		
4239.8	15	4239.8	10		
4242.4		4242.5	15		
4243.1	8	4243.4	1		
4245.1	12	4245.1	8		
4245.8	10			4246.0	
4246.8	75	4246.9	35	4246.9	80
4247.3	10	4247.3	7		
4248.1	10				
4250.1	18	4250.1	12	4250.1	15
4250.6	25	4250.7	12	4250.8	15
4251.6	8	4251.8	7		
4254.3	80	4254.3	25	4254.4	50
		4254.9	8 s		
4255.5	6				
4256.1	11	4256.3	6		
4257.0	4				
4257.5	7				
4258.0	20	4258.2	10		
4258.9	6				
4259.1	4				
4260.4	40	4260.4	20	4260.5	35

Cusp I		Adopted Wave-length	Comparison with Rowland's Table		
λ	I		λ	Substance	I
		4210.6	4210.49 4210.56	*Fe*	4 3
		4212.09	4212.05	*Zr*	2
		4213.90	4213.81	*Fe*	3
		4215.1			
4215.6		4215.70	4215.70	*Sr*	5 d ?
		4217.5			
		4217.8	4217.72	*La, Fe-Cr*	5 d ?
		4218.62	4218.56	*-Zr*	1 N d
		4219.59	4219.52 4219.58	*Fe*	4 3
4220.3		4220.46	4220.51	*Fe*	3
		4221.6	4221.63		1 N
		4222.74			
4223.0	30	4223.1			
		4224.2			
		4224.47	4224.34	*Fe*	4
		4225.52	4225.62	*Fe*	3
4226.6	40 h	4226.82	4226.90	*Ca*	20 d ?
		4227.67	4227.61	*Fe*	4
		4231.24	4231.18	*Ni*	4 N
		4232.6			
4233.3		4233.28	4233.33	*Mn-Fe*	4
		4233.78	4233.77	*Fe*	6
		4235.37	4235.30	*Mn*	2
			4235.45	*Mn*	3
		4236.10	4236.11	*Fe*	8
		4237.4	4237.34	*Fe*	3
		4238.1	4238.19	*Fe*	3
		4238.73			
		4239.0	4238.97	*Fe*	5
		4240.03	4240.01	*Fe*	3
		4242.67	4242.62		2
		4243.50	4243.52		1
			4243.61	*Fe*	3
		4245.37	4245.42	*Fe*	4
		4246.0			
4247.0		4246.97	4247.00	*Y?*	5
		4247.56	4247.59	*Fe*	4
		4248.3	4248.38	*Fe*	2
		4250.24	4250.29	*Fe*	8
		4250.89	4250.95	*Fe*	8
		4251.93			
4254.7		4254.51	4254.51	*Cr*	8
		4255.1	4255.13	*Fe*	2 d ?
		4255.7	4255.66	*Fe, Cr*	1
		4256.44			
		4257.2			
		4257.7			
		4258.32			
		4259.1	4259.11	*Fe*	2
		4259.3			
		4260.61	4260.64	*Fe*	10

Flash II		Cusp II		Flash I	
λ	I	λ	I	λ	I
		4261.2	12		
4261.8	25	4261.9	10		
		4262.6	4		
		4263.0	3		
4265.6	? 12	4265.9	7		
4266.8	20 d ?				
4268.5	8	4268.3			
		4269.9	7		
4271.0	20	4271.2	15	4271.1	9
4271 7	25	4271.7	35	4271.8	40
4272.7	6				
4273.2	20	4273.2	6		
4274.7	75 d ?	4274.7	30	4274.8	60
4275.4	20	4275.5	8		
4277.3	4				
4277.9	6 d ?	4278.0	3		
4279.6	8				
4280.5	5				
4282.2	25	4282.4		4282.5	12
4282.7	10			4282.8	15
4284.0	12	4284.0	6		
4284.6	3				
4285.2	8	4285.3	5		
4285.8	6				
4286.2	8	4286.4	5		
4286.6	3				
4287.7	25	4287.8	25	4287.7	12
4288.4	6	4288.6			
4288.7	4				
4289.6	40	4289.7	10	4289.7	50
4290.1	40	4290.2	20	4290.3	25
4290.9	12 d ?	4290.8	12		
4291.8	10	4292.0	18		
4292.9	7	4293.0	7		
4293.9	70	4294.0		4294.2	60
4294.5	7				
4294.9	5				
4295.8	7	4295.6	15		
4296.6	20	4296.5	20	4296.5	6
4299.0	5				
4299.9	60	4299.9	20	4300.1	50
4301.7	40	4301.7	15	4302.0	25
4302.2	12	4302.5	8		
4302.8	15	4303.0	12	4302.6	
4303.9	5	4303.4	8	4303.2	12
4304.2	5	4304.4	10		
4305.4	40				
4306.5	10	4306.6	12		
4307.8	50	4307.8	15	4308.0	45

Cusp I.		Adopted Wave-length	Comparison with Rowland's Table		
λ	I		λ	Substance	I
		4261.4	4261.38		2
		4262.09	4262.09		1
		4262.8			
		4263.2	4263.29	*Ti, Cr*	2
		4266.0	4266.08	*Mn*	2
		4267.0	4267.12	*Fe*	3
		4268.65			
		4270.1			
		4271.24	4271.33	*Fe*	6
		4271.89	4271.93	*Fe*	15
		4272.9			
		4273.48	4273.48	*Fe*	3 N
		4274.93	4274.96	*Cr*	7 d ?
		4275.72			
		4277.5			
		4278.21			
		4279.8	4279.87		2 N d ?
		4280.7			
		4282.50	4282.57	*Fe*	5
		4282.88	4282.86	*Ti*	0
		4284.27	4284.22	*Mn, V*	0
			4284.38		2 N d ?
		4284.8	4284.84	*Ni*	1
		4285.50	4285.53		1
			4285.61	*Fe*	3
		4286.0			
		4286.58	4286.63		3 N
		4286.8			
		4287.91	4288.04	*Ti*	2
		4288.7			
		4288.9			
		4289.82	4289.89	*Cr*	5
		4290.34	4290.38	*Ti*	2
		4291.11	4291.11	*Ti*	3
		4292.15	4292.14	*Cr, V*	0
		4293.17	4293.19		2
4294.5		4294.41	4294.30	*Fe*	5
		4294.7			
		4295.1			
		4295.98	4295.91	*Cr, Ti*	2
			4296.04	*Ni*	1
4296.4		4296.72	4296.74		3
		4299.2	4299.15	*Ca*	3
4300.49		4300.36	4300.38	*Mn*	0
		4301.96	4302.09	*Ti*	2
4302.3		4302.31	4302.35	*Fe*	2
		4302.95	4302.91		2 N
		4303.70	4303.75		1
		4304.51	4304.55		1
		4305.6	4305.61	*Fe, Si, Ti, Cr*	3
		4306.80	4306.86		2
		4308.01	4307.91	*Ca*	3
			4308.08	*Fe*	6

Flash II		Cusp II		Flash I	
λ	I	λ	I	λ	I
4308.6	5				
4309.4	30	4309.4	30	4309.8	12
4309.9	2				
4311.1	3	4311.4	6		
4312.7	40	4312.8	25	4313.0	
4313.3	8	4313.5	8		
4314.0	40	4314.0	20	4314.3	40
4314.9	40	4314.8	30	4315.1	35
4316.5	12	4316.6	6		
4317.0	6				
4318.5	20	4318.7	12	4318.8	4
		4319.5	6		
4320.7	60	4320.7	50 l	4320.9	45
4321.3	12	4321.6	8		
4322.8	7 h d ?	4323.0			
4324.8	40	4324.9	20	4325.1	20
4325.6	50	4325.6	30	4325.9	55
4326.8	15				
4327.6	7 h	4327.8	10		
4330.5	30 v h	4330.5	h		
4331.2	15 h				
		4332.7	6		
4333.5	25	4333.6	18	4333.0	15
4334.4	12				
4335.8	8				
4336.6	15	4336.1	6		
4337.6	25 s	4337.7	20		
		4339.2	12		
4340.63	400	4340.63	400		
4341.4	? 3	4341.9	8		
4342.9	10	4342.9	6		
4343.3	5	4343.4	5		
		4343.7	5		
4344.2	50	4344.2	25		
4345.6	8 h				
4347.5	25				
4348.6	7				
4351.5	60	4351.6	40		
4352.4	40	4352.6	30		
		4353.5	5		
4354.2	15	4354.3	12		
4357.7		4357.9			
4358.4	20 h	4358.5			
4359.4	40	4359.5	30		
4359.8	15 h				
4361.6	15				

Cusp I		Adopted Wave-length	Comparison with Rowland's Table		
λ	I		λ	Substance	I
		4308.8	4308.76		2 N d ?
		4309.71			
		4310.1			
		4311.50			
		4312.99	4313.03	*Ti*	3
4313.4	10	4313.55			
4314.12	10	4314.36	4314.25	*Sc*	3
4315.2	20	4315.28	4315.14	*Ti*	3
			4315.26	*Fe*	4
		4316.79			
		4317.2			
4319.2	15	4319.02	4318.82	*Ca, Mn?*	4
		4319.7			
4321.0	25	4321.06	4320.91	*Sc*	3
		4321.72	4321.12		2
		4323.1			
		4325.18	4325.15	*Sc*	4
4325.9	15 l	4326.03	4325.94	*Fe*	8
		4327.0			
		4328.06	4328.08	*Fe*	2
		4330.71			
		4331.4			
		4332.9			
		4333.54			
		4334.6			
		4336.0			
		4336.6			
4338.2	15	4337.99	4337.95	*Sr?*	00
			4338.08	*Ti*	4
4339.4	10	4339.42			
		4340.63	4340.63	*H*	20 N
		4342.1			
		4343.17			
		4343.56			
		4343.9	4343.86	*Fe*	2
		4344.42	4444.45	*Ti* –	2
		4345.8			
		4347.7	4347.71		1 N
		4348.8			
4351.8	15 l	4351.79	4351.71	*Fe*	2
			4351.93	*Cr*	5
		4352.75	4352.91	*Fe*	4
		4353.7			
		4354.47			
		4358.0			
		4358.70	4358.67	*Fe*	2
		4359.72	4359.78	*Cr*	3
		4360.0			
		4361.8			

Flash II		Cusp II		Flash I	
λ	I	λ	I	λ	I
4362.8	10				
4363.6	6	4364.0	8		
4364.3	8				
4365.9	5				
4367.3	25 h	4367.5	15		
4369.0	12				
4369.3	15	4369.4	25 d ?		
4370.8	20 d ?	4370.8	20		
4371.8	4				
4372.4	5				
		4373.7	6		
4374.7	60	4374.8	30	4374.5	12
4375.6	40	4375.8	20	4375.0	15
4376.3	5			4376.0	6
4376.8	15				
4378.8	30				
4380.3	15				
4381.3	10				
				4383.7	20
				4395.2	35
				4399.9	7
				4400.5	5
				4404.9	25
				4415.7	4 d
				4416.9	7
				4417.9	12 l
				4427.4	8

TABLE OF LINES MEASURED ON PLATES TAKEN WITH THE CONCAVE GRATING.

The table is in two parts. The first includes thirty-five lines in the spectral region covered by both the prism train and the grating. All but two of these lines have been given above from the measures on the prism plates, and accordingly the comparison with Rowland's table is not repeated, but the last column gives the difference, to the nearest tenth of a tenth-meter, between the wave-length found from the prism plates and the mean wave-length given in the third column which is obtained directly from columns first and second. This difference exceeds 0.2 tenth-meter in only four cases. When averaged with the wave-lengths above obtained on the prism-plates, with the

Cusp I		Adopted Wave-length	Comparison with Rowland's Table		
λ	I		λ	Substance	I
		4363.0			
		4364.0			
		4364.5			
		4366.1			
		4367.64	4367.75	*Fe*	5
		4369.2			
		4369.6	4369.94	*Fe*	4
		4371.0			
		4372.0			
		4372.6			
		4373.9			
		4374.8			
4375.2	25 l	4375.5			
		4376.3	4376.11	*Fe*	6
		4377.0			
		4379.1			
		4380.5			
		4381.5			
		4383.7	4383.72	*Fe*	15
4395.3	25	4395.27	4395.20	*Ti*	3
		4399.9	4399.94	*Ti, Cr*	3
		4400.5	4400.56	*Sc*	3
		4404.9	4404.93	*Fe*	10
		4415.7			
		4416.9			
4418.2	12	4418.0	4417.88	*Ti–*	3
4425.8	7	4425.8			
		4427.4			

proper weights, the change in the adopted wave-length in the previous table would not be affected in any case enough to change the identification with lines in Rowland's table. Two lines, at λ 4387.9 and at about λ 4398, were not measured on the prism plates. They do not appear to be readily identifiable with any of the stronger ones of Rowland's lines. The letter N is used to signify the normal or standard lines, fourteen in number, by which the wave-lengths were reduced. The Rowland values of their wave-lengths are given instead of the values computed from the least square solution, which, of course, would differ slightly from them. As explained above, a constant correction of +0.2 tenth-meters has been applied to all the wave-lengths measured on Flash II. A colon indicates that the measures on a line were recorded in the original notes as rough or uncertain.

In the second part of this table the comparison with Rowland's table is given in the same manner as in case of measures on the prism plates.

BRIGHT LINES MEASURED ON SPECTRA TAKEN WITH CONCAVE GRATING.

I. LINES ALSO OBTAINED WITH PRISM-TRAIN.

Flash I		Flash II		Mean λ	Difference Prisms-Grating λ
λ	I	λ	I		
N	90	N	70	4215.70	0.0
N	60	N	45	4226.90	0.0
4233.3	12	4233.4	30 h	4233.4	—0.1
4246.9	50 l	4247.2	35	4247.1	—0.1
4250.5	7 h	4250.2:	3	4250.4:	—0.2
4254.5	35	4254.5	25 s	4254.5	0.0
		4258.1	7	4258.1	+0.2
4260.7	8	4260.3:	10 h	4260.5:	+0.1
4271.8	18	4271.8	12	4271.8	+0.1
N	30	N	20	4274.96	0
N	45	N	30	4289.88	0
4294.2	25	4294.4	20	4294.3	+0.1
4300.4	30	4300.2	25	4300.3	+0.1
		4303.3	30	4303.3	[0.0 pair]
		4305.6	5	4305.6	0.0
N	25	N	25	4307.90	+0.1
4313.2	11	4312.8	15	4313.0	0.0
4314.4	14	4314.9	35	4314.4	0.0
4315.3	12			4315.3	0.0
		4318.6	7	4318.6	+0.4
4321.0	20 s	4321.1	25	4321.1	—0.3
4325.8	25 h	4325.7	40 d?	4325.8	+0.2
4328.5	15 l				—0.4
N				4340.63	0.0
		4344.1	10 s	4344.1	+0.3
4352.2	30 l	4352.0	45	4352.1	[+0.2 pair]
		4359.5	15 h	4359.5	+0.2
4375.1	20	4374.9	25	4375.0	[+0.1 pair]
		N		4383.72	0.0
4387.9	10 d			4387.9	—
4395.2	50 l	4395.3	50	4395.2	+0.1
		4397.8:	8	4397.8:	—
4400.2	25	4400.4	30	4400.3	+0.2
N	18	4404.8	20	4404.93	0.0
4417.8	18 h	4418.2	30 h	4418.0	0.0

II. LINES BEYOND LIMIT OF PRISM SPECTRA.

Flash I		Flash II		Mean λ	Comparison with Rowland's Table		
λ	I	λ	I		λ	Substance	I
		4408.1:	8	4408.1:	4407.87	*Fe*	4
4415.6	12	4415.2	20	4415.4	4415.29	*Fe*	8
4427.5	12 h	4427.2	12	4427.4	4427.27	*Ti*	2
					4427.48	*Fe*	5
		4429.7	8	4429.7			
4435.0	10 d?	4435.3	10	4435.2	4435.13	*Ca*	5
					4435.32	*Fe*	2
4444.0	40	4444.0	35	4444.0	4443.98	*Ti*	5
4450.6	18	4450.6	20	4450.6	4450.65	*Ti?*	2
4454.9	12	4454.9	20 h	4454.9	4454.95	*Ca, Zr*	5
		4457.8	5	4457.8	4457.60	*Ti, V, Zr,*	2
					4457.71	*Mn*	2
4461.9	7	4461.7	15 d	4461.8	4461.82	*Fe*	4
4464.6	6	4464.6	12	4464.6	4464.62	*Ti?*	2
4468.8	50	4468.8	30 s	4468.8	4468.66	*Ti-*	5
N		N	100	4471.65	4471.65	*He*	
		4482.1		4482.1			
		4489.2	8	4489.2			
		4491.4	10	4491.4			
		4494.5	8	4494.5			
		4496.3:	6 d	4496.3:			
N	35 l	N	35 l	4501.44	4501.44	*Ti,-*	5
4508.7	7	4508.0	15	4508.4	4508.66	*Fe?,-*	4
		4511.7	4	4511.7			
4515.5	10	4515.3	12 h	4515.4	4515.51		3
		4518.0	5	4518.0			
4520.5	8	4520.3	17	4520.4	4520.40	*Fe?,-*	3
4522.9	15	4522.7	25 l	4522.8	4522.80		3
					4522.97	*Ti*	2
		4525.0	7	4525.0	4525.31	*Fe*	5
		4528.6:	5	4528.6:	4528.80	*Fe*	8
4534.2	40 l	4534.3	60	4534.2	4534.14	*Ti-Co*	6
4549.8	40 l	4550.0	55	4549.9	4549.81	*Ti-Co*	6 d?
N	50 l	N	55	4554.21	4554.21	*Ba*	8
		4556.1	10	4556.1	4556.31	*Fe-Cr*	4
4559.0	15	4558.8	15	4558.9	4558.83	*Cr?*	3
N	30	N	40 d	4563.94	4563.94	*Ti*	4
N	45	N	45	4572.16	4572.16	*Ti*	6
		4580.1:	5	4580.1:	4580.23	*Cr*	3
4584.1	25 l	4584.1	35 s	4584.1	4584.02	*Fe-*	4
4588.3	15 s	4588.1	13 l	4588.2	4588.38		3
4590.1	12	4590.1	10 l	4590.1	4590.13		3
		4616.3	15	4616.3	4616.31	*Cr*	4
4619.0	8	4618.7	12	4618.7			
		4619.8	6	4619.8			
4626.6	6			4626.6			
		4629.4	45 l	4629.4	4629.52	*Ti-Co*	6
4631.7	12			4631.7			
		4633.8	10	4633.8			
		4646.2	12 l	4646.2	4646.35	*Cr*	5

II. LINES BEYOND LIMIT OF PRISM SPECTRA.—*Continued.*

Flash I		Flash II		Mean λ	Comparison with Rowland's Table		
λ	I	λ	I		λ	Substance	I
		4651.1	7 l	4651.1			
		4656.8	7	4656.8			
		4662.7	10 d	4662.7			
		4666.6	15	4666.6	4666.66	*Cr*	1
		4669.6:	12	4669.6:			
4685.8	8 l	4685.6	8 l	4685.7			
N		N	30 vl	4713.18	4713.18	*He*	
		4804.3	20	4804.3			
		4823.0	15	4823.0			
4848.3	15	4847.4	25 l	4847.9:			
4855.3	8	4853.9:	20 l	4854.6:			
N	600	N		4861.63	4861.63	*Hβ*	30
4875.5	l			4875.5			
4924.2:				4924.2:	4924.11	*Fe*	5
4934.2:				4934.2:	{4934.21 / 4934.28}	*Ba-Fe?*	6

The number of bright lines included above is 382, of which 319 were measured on the prism plates; 241 lines, or 63 per cent. of the whole number have been identified, with a pretty high degree of certainty, with 260 of the stronger lines of Rowland's table. We shall obtain a more correct representation of the facts if we limit ourselves to that portion of the prism plates which were in best focus, namely, from about λ 4060 (from which point toward violet the notes with the measures on both Flash II and Cusp II record the focus as "getting poor") to λ 4310. Here we find 230 bright lines, of which 160, or 70 per cent. are identified with 176 of Rowland's dark lines.

This large percentage of identifications was not anticipated, in view of the contrary results so far published by Sir Norman Lockyer from examinations of the eclipse plates of 1893 and 1896, nor was it realized in the preliminary examination of our own plates; on the completed reduction of the measures it appeared, however, as indisputable.

But we cannot obtain an entirely fair idea of the relationship of the bright and dark lines until we consider the percentage of Rowland's dark lines that were not measured as bright on the

plates. In the region considered, λ 4060 to λ 4310, we find in Rowland's table 66 lines of intensity 3 or over, which were not measured as bright on these plates, either because of haziness or faintness or because they were actually absent. In making this count, lines so close to others already identified as to probably merge with them on the plates are excluded, and pairs that could not be resolved by the prism train are considered as single lines. It will be recalled that a line of intensity 1 is just clearly visible on Rowland's map. If we now exclude from the above 160 lines, 55 of which were identified with dark lines of intensity less than 3, we have 105 remaining for comparison. Thus it appears that of 171 of Rowland's lines 61 per cent. were measured as bright on the plates. This represents a minimum percentage, since a special search for the missing lines would doubtless reveal many of them as faint objects on the plate. Moreover, the two plates most rich in lines had to be measured, on account of the continuous spectrum present, at some distance from the point of third contact, so that the shorter lines could not be expected to appear. Any improvement in the definition of the plates or of the exposure time would undoubtedly increase the number of bright lines found.

Hence we reach the very important conclusion that at least 60 per cent. (and probably many more) of the stronger dark lines of the solar spectrum are found to be bright in a stratum not exceeding (for the great majority of the lines) 1″, or less than 500 miles in height above the solar photosphere. There is, moreover, no reason in general to suppose that this is not equally true of the fainter lines. Therefore we may regard the existence of a reversing stratum at the base of the chromosphere as fully confirmed by the photographs.

The results here obtained are very different from those presented by Sir Norman Lockyer in his *Recent and Coming Eclipses*, p. 111. He there contrasts the 164 and 464 bright lines between F and K photographed respectively at the eclipses of 1893 and 1896, with the total number of lines, 5694, in Rowland's table for that region, and he finds the percentages 3 and

8, respectively. It is obvious that the only comparison which would be reasonable would be with the number of dark lines which his instrument would photograph just before or after totality, which would be but a small fraction of Rowland's 5694.

The chemical origin of the bright lines identified with 260 of the lines of Rowland's table is as follows: iron 102, titanium 23, chromium 11, and double assignments involving one or more of these three, as *Fe, Zr* or *Fe, Cr*, 26. Thus 62 per cent. of the lines are attributable to these three elements. Five lines are due to each of these: *Ca, Mn, V;* four each to *Ni, Sc, Zr;* three each to *H, He, Sr, La, Co, C;* two to *Ba*, and one each to *Ce, Nd*, and *Y?*. Forty-one of the lines are assigned to no element by Rowland. No particular relationship to chemical classification is apparent in these lines: *Fe, Ti*, and *Cr*, have atomic weights of 55, 50, and 52; but other elements with similar atomic weights, as *Mn, Co, Ni*, are not conspicuous by their presence.

The fewness of the nickel lines might be thought rather surprising, as Rowland places nickel second in the order of the elements in the Sun according to number of lines. This is explained, however, by the fact that there happen to be very few strong lines of this element in this particular region of spectrum.

The identification of the three lines assigned to carbon is rather dubious, so that we must consider the evidence of the plates indecisive in respect to that element.

Eight lines of the spectrum of helium would fall within the range of our plates, but only three are conspicuous, those at λ 4026.3, 4471.6, and 4713.3. The lines at λ 4120.97 and λ 4143.9 are possibly present; while those at λ 4169.1 and λ 4388.1 were not recorded. The line at λ 4922.1 would be too near the edge of the grating plate for certain detection.

Of the 66 "missing" lines of intensity 3 or over, 41 are due to *Fe*, 4 to *Ca*, 3 to *Mn*, 1 to *Ti*, 1 to *Ce*, 8 are doubly assigned (in nearly every case involving *Fe*), and 8 are not identified by Rowland. The case of manganese seems peculiar, for if we examine the missing lines over the whole range of the prism plates we find

not less than 11 strong *Mn* lines which were not measured as bright, beside some double assignments involving *Mn*. We should infer that the gaseous stratum of that element must lie very close to the photosphere.

It would be of the greatest interest to give a comparison of these results with those obtained by parties under Sir Norman Lockyer's direction in 1893, 1896, and 1898, and with those deduced from the excellent photographs of Mr. Evershed in 1898. Unfortunately, however, the wave-lengths of the lines on the spectra obtained by these observers, with a discussion of their chemical origin, have not yet been published.

These plates give no evidence of any relationship between the bright lines and the "enhanced" lines, or lines distinctly more intense in the spark than in the arc spectrum, although Sir Norman Lockyer has attached much significance to a supposed connection between them. Some of the enhanced lines are present, and others are not, or at least were not conspicuous enough for measurement. It is quite probable that they afford identifications of the chemical origin of some of the lines not assigned to any element by Rowland. Taking Lockyer's recent list[1] of enhanced lines we may perhaps thus ascribe to iron the following unassigned lines of our tables above (Rowland's intensities are added): λ 4179.02 (3), 4296.74 (3), 4489.35 (2), 4491.57 (2), 4508.46 *Fe*,– 4, 4515.51 (3), 4520.40 *Fe?* (4), 4522.80 (3), 4556.06 (3). Of the 16 remaining enhanced lines of iron in the region covered by prism and grating plates, eleven (λ 4048.76 possibly to be excepted) do not occur in our table of bright lines; four were already assigned to iron in Rowland's list, while Lockyer's λ 4351.93 appears of identical wave-length with Rowland's *Cr* line of intensity 5.

In case of titanium, for which Lockyer gives 48 enhanced lines within our limits, we may summarize the comparison as follows: 17 lines do not appear as bright on the eclipse plates; one pair is doubtful; the remainder occur as quite strong lines of the ordinary dark line spectrum, and hence would be expected to

[1] *Proc. R. S.* **65**, 452, 1900.

appear in the reversing layer, as they do. Three lines of our table not assigned by Rowland to any element may be ascribed to titanium, viz., λ 4173.71 (3), 4184.87 (2), and 4590.13 (3).

The unassigned lines at 4242.62 (2) and 4284.38 (2 N d?), may be attributed to chromium; that at 4205.24 (1) to vanadium; the comparison with enhanced lines of manganese yields no results.

The "missing" bright lines on these eclipse plates also indicated no relationship to the enhanced lines.

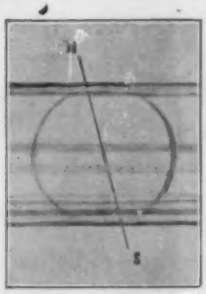
CORONAL PLATE.

Aside from the use of one red-sensitive plate, without expectation of securing any impression, but one exposure was made to the coronal spectrum, and that with the large dispersion and small range of the prism-train. If another observer had been available for working the concave grating, a plate would have been taken with it, but as the flash spectra were the particular objects of our attention, it did not seem safe to jeopardize the second flash by any further operations.

As already stated, the prism train was set at minimum for λ 4227 with especial view to securing a good image of the coronal ring at λ 4230. The exposure was begun as soon as the plate-holder could be adjusted after the exposure to the first flash, or from 5 to 10 seconds thereafter, and was continued for about 30 seconds. An exposure during the whole available time of totality would have been more suitable, in view of the apparent unusual faintness of the gaseous coronal spectrum at this eclipse.

The plate shows a very strong continuous spectrum, obviously coronal in its origin, from a source hardly more than 1′ greater in diameter than the solar photosphere. The continuous spectrum has apparently superposed upon it several longitudinal streaks of still greater intensity. This may be seen in the accompanying sketch of the appearance of the coronal ring at λ 4230, which represents the streaks and ring in approximately

their correct relative intensities on the plate. These streaks seem to bear no relation to the position of the prominences, nor can they be connected with any details of the inner corona as seen on the large scale photographs obtained by Professor Barnard and Mr. Ritchey. They were noted by Professor Campbell on his India plates, and probably by others, but a satisfactory explanation of their origin, at least in the present case, is not apparent.



No dark lines can be detected on the plate.

The plate shows most conspicuously the chromospheric arcs of $H\gamma$, $H\delta$, and the strontium radiation at $\lambda 4078$.

The strontium arc at $\lambda 4215$ is of about equal intensity with the coronal ring at 4230. The remaining arcs and rings are exceedingly faint and almost beyond measurement under a microscope, so that the determinations of the wave-lengths cannot pretend to any high degree of accuracy. In measuring the plate the settings were made on the relatively sharp, concave edges of the arcs and rings, near the position angle of first contact. $H\gamma$, $H\delta$, and $Sr\,\lambda 4078$ were the standards used in determining the constants of the formula. An approximate measure of the extent of the arc is given along with a rough estimate of its relative intensity.

MEASURES ON CORONAL PLATE.

Arc or ring	I	λ	Element	Origin
Arc 80°	20	4077.9	*Sr*	Chromosphere
Arc 90°	40	4102.0	*H*	"
Arc 80°	10	4215.4	*Sr*	"
Ring	8	4230.4	?	Corona
Ring	3	4311	?	Corona (?)
Arc 120°	50	4340.6	*H*	Chromosphere
Ring	6	4358	?	Corona

In addition to these arcs and rings faint traces of curved markings were noted at about $\lambda 4089$ (a pair?), 4137, and 4192,

but their reality is questionable, and it is not possible to estimate their extent as arcs.

The principal prominences on both limbs of the Sun are visible on this plate, and the broken appearance they give to the chromospheric arcs is in marked contrast to the uniformity of the coronal rings.

As shown by the sketch, the ring at λ 4230 is nearly of uniform intensity and shows no detail which can be brought into relationship with the large scale coronal photographs. It impressed itself upon the plate only to a distance corresponding to about 40″ from the Sun's limb.

SUGGESTIONS OF IMPROVEMENTS IN INSTRUMENTAL EQUIPMENT.

In addition to objective-prism or objective-grating cameras, it is desirable that slit spectrographs be employed, with comparison spectra of iron and titanium, in addition to the solar spectrum.

If concave gratings are employed, it is important that the plates or films should be bent to the proper radius.

Assuming that simple apparatus like that described in this paper is to be used, instead of elaborate automatic appliances, it would certainly be desirable to use a magazine plate-holder of quick action, giving a small plate to each exposure rather than several exposures on a single plate. Such a plate-holder as that described by Sir Norman Lockyer (*Recent and Coming Eclipses*, p. 87), would seem very suitable.

It would be of decided advantage in the subsequent measurement and discussion of the plates if each exposing shutter was connected with a chronograph, so that a record could be obtained of the exact instant of each exposure.

CONCLUSIONS.

In concluding this paper, which has been much more protracted than was originally intended, the principal results may be summarized as follows:

The experience, principally of Sir Norman Lockyer and Mr. J. Evershed, is confirmed, that useful results may be obtained,

without much risk of failure, by the employment of the simple objective-prism camera.

It is shown that the concave grating, used direct, without intervention of mirrors or lenses, will furnish sufficiently bright images of the flash spectra, and probably of the corona, for useful measurement and discussion.

It appears that spectra photographed with such instruments just before or after totality (within about 30 seconds of the times of contact) yield quite as valuable results as those taken at the precise instants of contact.

It is demonstrated that the stronger dark lines of the solar spectrum are in a large proportion reversed in a narrow stratum at the base of the chromosphere, and the evidence indicates that this is equally true of the fainter lines.

The differences in intensities of the bright and dark lines are chiefly due to an increase in the intensities of the former, especially for such elements as strontium, rather than to a decrease in the intensities of the latter.

The chemical origin of the dark lines which are reversed is found in elements which are among those most numerously represented in the spectrum. This tends to show that the reversal is not an inherent peculiarity of special elements, but rather a phenomenon of lines in general.

YERKES OBSERVATORY,
December 4, 1900.

CELESTIAL PHOTOGRAPHY WITH THE 40-INCH VISUAL TELESCOPE OF THE YERKES OBSERVATORY.

By G. W. RITCHEY.

THE great power of the 40-inch telescope as compared with that of the 12-inch is strikingly shown in visual observations of such objects as the dense globular star-clusters. The visual limit of the 12-inch is at about 14.5 magnitude of Pogson's scale, while that of the 40-inch is at about 16.5 or 17 magnitude. As comparatively few of the stars composing the globular clusters are brighter than the 14.5 magnitude and several thousand stars at least, in most of them, are brighter than 17 magnitude, the great difference in the appearance of these superb objects in the two instruments is readily understood. Not less important than the superior light-gathering power are the greater scale and resolving power of the larger instrument, which are necessary to show even moderately well separated the stars composing the dense central parts of these wonderful masses.

The work of measuring accurately with the micrometer the positions of a large number of stars in these clusters is very laborious; to measure in this way all the stars seen with the 40-inch telescope in such a cluster as *Messier 15 Pegasi*, for instance, would be a stupendous task indeed, especially since it is only on rare occasions of very fine seeing that the fainter stars can be seen sufficiently well for satisfactory measurement.

The fine photographs of globular clusters obtained by Scheiner, the Henry Brothers, Leavenworth, and others, with photographic refractors of moderate size, and the excellent results obtained by Keeler with the Crossley reflector show unmistakably the great value of the photographic method in the study and measurement of these difficult objects.

It seemed highly desirable to find, if possible, some way to utilize for such photographic work the great power of the 40-inch

visual telescope. In November 1899 a number of thin plane-parallel plates of glass were prepared and coated with collodion of a delicate greenish-yellow tint, which, when tested with the spectroscope, was found to effectually shut out the blue end of the spectrum, while transmitting the green, yellow, and red without appreciable diminution of intensity. Several very perfect color-screens of excellent quality and of different densities were thus secured for preliminary trials. A special plate-holder was constructed, the color-screen being mounted in the plate-holder, in contact with the sensitive plate. Cramer's instantaneous isochromatic plates are used, these being extremely sensitive to yellow light, while their sensitiveness falls off rapidly in the orange and red, on the one side, and in the green on the other, increasing again in the blue.

It will be noticed that this combination is a promising one for sharpness, as only a short region of the spectrum, for which the color-curve of the 40-inch objective is very nearly flat, is used in producing the photograph. All other rays, which are of course out of focus, and would therefore injure the sharpness, are effectually cut out, the blue by the color-screen, the red, orange, and much of the green by the non-sensitiveness of the plate for these rays. Nor is this combination an unpromising one for speed, taking into account the extreme sensitiveness of the plates for yellow light, when used with a very large and thick objective such as the 40-inch, as compared with the ordinary blue sensitive plate used with a photographic objective of the same size and thickness. Professor Vogel says that no less than 51 per cent. of the photographic light is lost in transmission through the new 32-inch photographic objective at Potsdam, although in that case the glass used was carefully selected for photographic purposes; the loss of yellow light is 33 per cent. It is estimated that between 60 and 70 per cent. of the blue light is lost in transmission through the 40-inch objective, while about 35 per cent. of the visual rays are thus lost.

It was hoped, therefore, that this combination of isochromatic plate and yellow screen, used with the 40-inch telescope,

would give very sharp photographs with reasonably short exposures. In the earlier trials of this process, which included the photographs of the cluster *Messier 13 Herculis*, plates were used which were considerably less rapid than the last lot of plates furnished by the Cramer Company, and it is confidently expected that plates still more sensitive to yellow light can be furnished soon. With the present plates, and with fine seeing, sixteenth magnitude stars are photographed with sufficient intensity for measurement with one hour's exposure. The diameter of the images of the fainter stars is less than one second of arc.

The plane-parallel color screens used in the trials of this process are 2.4 mm thick and cover a field 14 minutes of arc square at the focus of the 40-inch telescope. There is, of course, a slight radial distortion of field introduced by this form of screen, amounting for the dimensions given to about 0.″03 at edge of field, where it is greatest. There is also some uncertainty introduced by the use of the collodion film, even when this is separated from the sensitive plate by only one tenth of a millimeter. The star images at edge of field are as perfect in shape as those at the center, no difference whatever being perceptible under high magnification.

A color-screen of optical glass of the proper yellow tint, and of the form of a thin concavo-convex lens, properly mounted, held by three points of its edge, in a metal plate-holder, close in front of the sensitive plate, and with the curvature of the two surfaces such that the center of curvature of each is at the optical center of the objective, would introduce no distortion of field perceptible under the most refined measurement, for fields 30 minutes of arc in diameter. Several color-screens of this form will soon be prepared for use with the 40-inch telescope. It is needless to say that for photographs intended for accurate measurement the glass used for the photographic plates themselves should be ground and polished approximately flat, as was done in the case of the plates used for the Potsdam photographs for the *Carte Celeste*.

The guiding device or sliding plate-carrier for long exposures is somewhat similar to that described by Dr. Common in *Monthly Notices*, **49**, 297; it was constructed in a very perfect manner by Mr. Johannesen, the observatory instrument maker. The plate-holder is carried on two slides, at right angles to each other, and is movable by two fine screws, the milled heads of which are held in the observer's fingers. A guiding eyepiece giving a power of 1000 diameters with the 40-inch telescope is mounted on the frame to which the plate-holder is rigidly attached; the eyepiece can be moved in two directions on this frame, so that a suitable guiding star near the edge of the plate can be found. Fine "cross-wires" of silk fiber are illuminated by red light from a small incandescent lamp mounted at the side of the eyepiece, the light being controlled by a rheostat. A light flap is arranged so that it can be turned down instantly over the plate if anything goes wrong.

By this simple arrangement the full power of the 40-inch telescope is used in guiding. This guiding, with the high power used, is very different indeed from guiding with the 12-inch telescope. Even under the best conditions incessant small movements of the image, due chiefly to the atmosphere, but partly to the instrument, render necessary continual guiding by means of the two screws which move the plate-holder. It should be noted that the greater part of these minute irregular movements could not possibly be detected with the 12-inch telescope, but are distinctly visible with the 40-inch. The plate-carrier is so light, and the slides and screws are so well made, that guiding in this way can be accomplished with very great delicacy and quickness, as compared with what could be done if the usual method of moving the entire telescope by means of slow motions were employed; this will be readily appreciated when I state that on an average no less than sixty movements of the screws per minute are necessary, even under the best atmospheric conditions. Generally as careful guiding is required under fine conditions as under ordinary ones, because the movements of the small sharp image, though shorter and less rapid, can be

seen much better than those of the nebulous image present under poorer conditions. Experience has shown that to obtain the sharpest results and the roundest possible star-images the observer must not take his eye from the guiding eyepiece nor his fingers from the screws for an instant without first turning down the flap over the plate; this is done even when the observer moves his chair and when the assistant is changing the height of the elevating floor. The flap is very useful also when sudden disturbances of any kind occur, such as those due to the slight shifting of the objective in its cell, the slight jar caused by the longitudinal slipping of the declination axis in its sleeve, and sudden blurring of the image due to atmospheric causes.

There are two evident objections to the use of such a sliding plate-holder; one is that the position of the images on the photographic plate is continually changing slightly, during the exposure, with reference to the optical axis of the objective; without proper precautions this might sensibly affect the measurability of the photographs. In the work with the 40-inch telescope the slides allow a motion of only six millimeters (about one minute of arc) on each side of the center, and there is no objection to reducing this range of motion by suitable stops to fifteen seconds of arc or less, since all that is necessary when the slides are moved to the stops is to cover the plate while the slides are brought back to the starting point, and the guiding star again centered on the cross-wires by means of the telescope's slow motions. This operation is accomplished in less than half a minute, and with the superb performance of the great driving-clock would not be necessary oftener than each half-hour, for the range suggested.

The other objection is perhaps more serious. In the work of photographing the globular clusters with the 40-inch, $3\frac{1}{4} \times 4\frac{1}{4}$ and 4×5 plates are used, so that in general the guiding star is about 2 inches, or 8 minutes of arc, from the center of the plate and of the cluster. As the zenith distance of the object is constantly changing during the exposure, there is a slight change in the amount of the differential refraction between the guiding

star and the stars of the cluster. In order that the effect of this change shall be as small as possible, the following conditions should be realized: (1) the exposure should be equally distributed east and west of the meridian; (2) for such an exposure a guiding star should be selected having as nearly as possible the same hour-angle as the object being photographed; (3) the total time covered by the exposure should be as short as possible for plates intended for measurement.

In spite of the objections named, the use of the sliding plate-holder in guiding seems indispensable with very large photographic telescopes, if the sharpest possible results are to be secured. With the 40-inch it would certainly be impossible to guide properly if the entire mass of the telescope had to be moved by means of slow motions, however perfect. Furthermore, the problem of mounting side by side, for example, two 40-inch objectives—a photographic and a visual for guiding—with such stability in their cells that there would be no relative shift of the two sufficiently large to produce a sensible change in the relative position of the photographic and guiding images at the eye-end, 63 feet away, would present very serious if not insurmountable difficulties.

A severe test of the new method is afforded in photographing such an extremely dense globular cluster as *Messier 15 Pegasi*, a fairly satisfactory negative of which was obtained on the night of October 3, with an exposure of three hours. My experience with seeing conditions during this exposure may be used to illustrate the difficulties encountered, though these conditions were better than usual. The exposure was begun with the seeing moderately good, 7 on a scale of 10. The conditions improved gradually for 130 minutes, though they were occasionally so bad for short intervals that the plate had to be covered. During the last 50 minutes of the exposure the seeing was as fine as I have ever had, the guiding star appearing as a hard brilliant point. After 50 minutes of such seeing a chill wind sprang up suddenly, which instantly destroyed the good definition; the image of the twelfth magnitude guiding star

became so large and nebulous that it was seen with difficulty and was at instants entirely obliterated.

Professor Barnard concurs in the opinion that the faintest stars distinctly shown on the resulting negative are as faint as can be seen with the 40-inch telescope under the most perfect conditions. The negative is very sharp, but would be better—the brighter stars smaller and the dense center of the cluster better resolved—if only the last two hours of the exposure time had been used; the very faint stars would be shown fully as well, as it is only under fine conditions that these photograph at all. Many faint double stars in this cluster, with magnitudes down to 16.5 or 17, and distances down to 1″, are distinctly shown and sharply separated on the negative. Multitudes of faint stars which are involved in the glare about the center of the cluster are much more easily seen on the photograph than with the telescope direct; this is true in the case of all the globular clusters.

This peculiarity is very noticeable also in the case of faint stars involved in nebulosity, as for instance, Barnard's faint double star just preceding the *Trapezium* of *Orion*, which is described by Professor Burnham in *Monthly Notices*, **49**, 354, as follows: "I was unable to see the two components on any night when it was measured from the bright stars of the *Trapezium;* later on a remarkably perfect night I saw the minute pair well, though with great difficulty, and obtained a fairly good measure; as a double star it is quite unlike anything known in the heavens, and the severest possible test for the defining and illuminating power of the great (Lick) telescope; I have only been able to see it once." This star has been repeatedly photographed with the 40-inch with 45 minutes' exposure, though I have not yet had an opportunity of trying it under first-class conditions; with this exposure and with seeing 8 on a scale of 10 it is strongly shown, very distinctly elongated. Under the best conditions it should be shown well separated with an exposure of less than 45 minutes. The distance given by Burnham is 1″.3, and the magnitudes are 16 and 16.5. Eighteen stars certainly

fainter than this double are shown on the negative within a distance of one minute of arc from the center of the *Trapezium*. It should be noted that the magnitudes determined from these photographs must closely approximate those obtained visually.

On the negatives of *Messier 13 Herculis* above referred to the center of the cluster is well resolved; on the best negatives lines and groups of stars of about the sixteenth magnitude, with distances down to 1″, are well shown and distinctly separated. One of Barnard's doubles, in which the magnitude of the components is 14.5 and the distance 1″.3, is very strong, and is sharply separated; it is called by him very faint, as it is near the central glare. Burnham's double, β1199, in the heart of the cluster, discovered with the Lick 36-inch, the magnitudes being 11.4 and 12.0 and the distance in 1899, 0″.97, is markedly elongated, but is too strong with the two-hour exposure to be shown separated; that a shorter exposure would show it separated is apparent from the fact that no less than 40 faint doubles of about 1″ distance are shown distinctly separated on the negative. On the best negative of this cluster there are 3200 stars in an area 10 minutes of arc square.

The illustration of the lunar crater *Theophilus* and surrounding region (Plate XXI) is from a negative obtained with the 40-inch telescope October 12, 1900. The enlargement, as compared with the original negative, is about 6 diameters. The full aperture of the telescope was used, and the exposure time was less than one half second.

The results obtained in this work demonstrate the effectiveness and importance of telescopes of great focal length for the photography of objects requiring great scale and separating power; for dense star clusters, double and multiple stars, the surface markings of the planets, and details of the lunar surface, the gain is apparently in direct proportion to the increase of focal length. The effect of aperture, and consequent resolving power, upon the quality of photographic results is in practice so complicated with the effects of seeing conditions, accuracy of guiding, sharpness of focus, and grain of photographic plate,

that it is probable that photographic telescopes with much greater ratio of focal length to aperture than is ordinarily used, would be desirable for the photography of the classes of objects referred to.

For such purposes a photographic telescope of 2 feet aperture and 200 feet focal length is being built in the optical and instrument shops of this Observatory. Work on the optical parts, which include a 30-inch and a 24-inch plane mirror and a 24-inch concave mirror of 200 feet focal length, was begun in December 1899 and is now well advanced. This instrument is of the horizontal type, with coelostat, but differs in many details from the instrument of very similar dimensions suggested by Dr. Common in his recent address before the British Association.

In the case of the horizontal telescope of 61.5 feet focal length used by Professor Barnard and the writer at the eclipse of May 28, 1900, the ratio of focal length to aperture is 123 to 1. Exquisitely fine structure in the chromosphere and prominences is shown on the negatives obtained with this instrument, and the richness and delicacy of detail of the corona leave nothing to be desired.

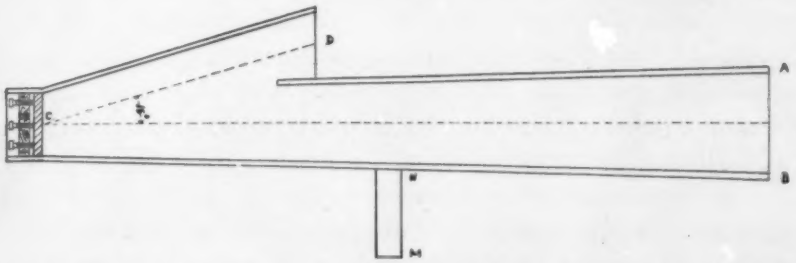
These results, obtained with a telescope of still greater ratio of focal length to aperture than that of the 200-foot, together with the stability and superb driving of this type of instrument; the high efficiency of the reflector in photography, so effectively demonstrated by Keeler; and the freedom of the reflector, when of great focal ratio, from many of the serious difficulties inherent in specula of large angular aperture: all seem to promise well for the success of the new instrument.

YERKES OBSERVATORY,
UNIVERSITY OF CHICAGO.
November 14, 1900.

THE REVERSING LAYER PHOTOGRAPHED WITH A CONCAVE ROWLAND GRATING.

By J. F. MOHLER and F. C. DANIEL.

ONE of the pieces of apparatus taken along with the Dickinson College Eclipse party on May last was a concave Rowland grating, 4 inches in diameter, ruled with 14,400 lines to the inch and of ten feet radius. It was enclosed in a box about five feet long and placed as indicated in the figure, where the grating is shown in position at *C* resting on three set screws. At *D* is an



opening 4 inches square to admit the light and provided with a tight-fitting cap. The photographic plate was placed at *A B* so that the middle of the plate would be on the axis of the grating. In this position the dispersion is nearly normal over the entire plate. At *A B* was a narrow slit about one eighth of an inch wide and seven inches long and back of the slit was a sliding plate-holder carrying a 5×7 Cramer instantaneous isochromatic plate. Two small wheels operated by a rod moved the plate across the narrow slit so that a series of exposures $\frac{1}{8}$ by 7 inches could be made on the same plate. The rod was operated by an observer looking through a small objective prism spectroscope attached to the outside of the box. The box was mounted on the declination axis *M N* of an equatorial mounting so that the lines of the grating would be tangent to the edge of the Sun at the places of contacts II and III. The angle *D C E* was about

16° so that the F line of the first order came near the middle of the plate and the spectrum extended from below D_3 to above G. The equatorial mounting was supplied with a fairly good clock, which followed the Sun's image very well.

The grating was used to form a diffracted image of the Sun's disappearing crescent without the use of lens or slit, in the same way that an objective prism spectroscope is used. The focal length of the grating used in this way is just about five feet and the Sun's image is about .56 inch in diameter.

When the Sun's crescent was so thin that the dark Fraunhofer lines could be distinctly seen in the prismatic spectroscope, which was about thirty seconds before totality, the cap was removed from *D* and a series of exposures of about one second each was made until the "flash" spectrum had disappeared. The plate was then moved forward a little and kept in position for about ninety seconds. The plate was moved forward again and another series of exposures made to catch the flash at third contact.

The results obtained were not quite as good as we had expected. The plate lacked in sharpness of definition. We had, however, timed the exposures nearly right and obtained about forty bright lines at the flash and perhaps sixty dark Fraunhofer lines on exposure before totality and only three distinct lines during totality. The measurement of thirty-two of the bright lines is given in the table below. This table gives the measured wave-length, the intensity of the bright line, and the element supposed to produce it. This last is taken from Rowland's table (this JOURNAL, Vol. I). Our measurements are only to Ångström units, as the lines were not sufficiently sharp for more accurate measurements.

The lines D_3, F and $H\gamma$ are by far the strongest lines in the flash, and also appear as strong lines in the long exposure made during totality. They appear on the plate as images of a prominence near the eastern limb of the Sun, and are of different shape for the light coming from the western limb of the Sun, both sets of images appearing on the same exposure. The

exposures made at the end of totality did not give as good results as the exposure to the first flash, as the position of the instrument had been altered a little in declination in moving forward the plate.

TABLE OF LINES SHOWING AT THE FIRST FLASH.

Line	Intensity	Measured Å	Substance	Line	Intensity	Measured Å	Substance
Hγ	12	4340	*H*		2	4638	*Fe*
	1	4376	*Fe*		2	4644	*Fe*
	1	4383	*Fe*		1	4654	*Fe*
	1	4395	*Ti*		1	4662	*Fe*
	2	4417	*Ti*		1	4666	*Ti* (*Fe*)
	2	4442	*Fe*	F(*Hβ*)	15	4861	*H*
	2	4470	*Fe*		1	4920	*Fe*
	2	4471	*Ti*		2	4923	*Fe*
	1	4502	*Ti*		1	4933	*Fe*
	1	4534	*Ti Co*		1	5017	*Fe Ni*
	1	4550	*Fe Ti Co*	b_4	2	5167	*Mg Fe*
	1	4556	*Fe Ti*	b_3	2	5169	*Fe*
	2	4563	*Ti*	b_2	3	5173	*Mg*
	2	4571	*Mg*	b_1	4	5184	*Mg*
	2	4582	*Fe*	1474 K	2	5316	
	1	4630	*Fe Ti Co*	D_3	10	5876	*He*

Although our list of lines is not extensive, and the accuracy of measurement only one Ångström unit, nevertheless the results lead us to think that very good results could be obtained in this way.

The lack of sharpness of the lines may be due to one or more of four causes:

1. The location should be such that the lines of the grating, when perpendicular to the Right Ascension circle, will be tangent to the disappearing and reappearing crescent of the Sun at contacts II and III. We were situated at the village of Pungo, Va., very near the central line of totality, but we did not make any observations for position. We arrived at Pungo on Friday, May 25, and the rain all day Friday and Saturday gave us short time to set up the instruments; we had no time for latitude and longitude observations, and no time to change position if we had found change desirable. Of course we could make the lines of the grating tangent to the Sun's crescent at

either contact II or III by giving the grating the proper inclination, but to get it tangent to the Sun at both contacts the instrument must be situated on the central line of totality.

2. With this form of mounting, the clock must follow exactly the motion of the Sun, as any drift in R. A. will spread out the lines. In trials with the instrument before the eclipse the clock was running just about right. All these trials were made without the plate-holder in position, and when the plate-holder was put on the end of the box the instrument was so exactly balanced in R. A. that there was not enough weight either way to take up the lost motion of the driving-screw, and for that reason the lines show some irregular drift in the successive exposures.

3. The focusing of the grating must be done with a collimator, and while this had been accomplished before leaving Carlisle, we found that it had to be repeated when we arrived at Pungo, where with the facilities at hand the work could not be done very accurately. The plate may have been, and doubtless was, somewhat out of focus.

4. The astigmatism of the grating: This property of the concave grating has doubtless been the cause of its rejection for this class of work, and the substitution of the objective prism. The amount of astigmatism has been worked out by Dr. S. A. Mitchell [*Johns Hopkins Circular*, June 1898], and for a point source of light is given by the formula:

$$a = -Z + Z\sqrt{r\left(\frac{\cos\gamma + \cos\mu}{\rho} - \frac{1}{R}\right)},$$

where a is the length of the image of the point, Z the length of the lines on the grating, r the distance of the image from the grating, R the distance of the point source of light from the grating, ρ the radius of grating, and μ and γ the angles of incidence and reflection. Using the grating as we did, $\mu = 0°$, $R = \infty$, $r = \frac{1}{2}\rho$, therefore

$$a = -Z + Z\sqrt{\frac{\cos\gamma + 1}{2}}.$$

Now if $\gamma = 16°$ and $Z = 1\frac{1}{2}$ inches, $a = .015$ inch.

The image of the Sun with a mirror of this radius is about .56 inch in diameter. With a slit ⅛ inch wide, the extreme blurring at the edges due to this cause would be .0096 inch, and in the middle of the strip the widening of the lines would be only .0004 of an inch. With a slit $\frac{1}{16}$ of an inch wide the spectrum would still be wide enough to measure easily, and the extreme blurring would be less than .003 of an inch; lines as fine as this are nearly as good as can be obtained on a rapid photographic plate.

If no slit at all is used, and the Sun's entire image is photographed, the astigmatism would blur the edges at the poles about .03 of an inch, *i. e.*, there would be a shading .015 of an inch wide above and below the true image. This effect might be made less by using a grating of fewer lines to the inch, or by using light of shorter wave-length. The great advantage of using a concave grating in this way is that there is nothing in the instrument to absorb the radiations coming from the Sun. In common with the objective prism it has the disadvantage that no comparison spectrum can be photographed alongside of the solar lines, but it has the advantage over the prismatic spectroscope that the spectrum is normal. Our partial success leads us to believe that the instrument could be used to great advantage in obtaining the spectrum of the flash.

DICKINSON COLLEGE,
October 26, 1900.

FIRST RESULTS OF INVESTIGATIONS ON THE OBSERVATION OF THE SOLAR CORONA WITHOUT AN ECLIPSE BY MEANS OF THE HEAT RAYS.[1]

By H. Deslandres.

The corona, which is the highest, the most extensive, and the most mysterious portion of the solar atmosphere, has not hitherto been observed without a total eclipse. However, several attempts have been made to observe and to photograph it under ordinary conditions, in particular by Sir W. Huggins in 1885, by Messrs. Hale and Riccò in 1893 and 1894, and by myself from 1891 to 1893.

In February 1894 (*Bulletin Astronomique*, p. 66) I described a new method of accomplishing the result. The previous attempts had been made with the visible and ultra-violet rays; but these rays are too intense in the diffuse light of our sky, which is the obstacle interposed between us and the corona. However, for reasons too long to be repeated here, the difficulty is considerably diminished with the extreme infra-red rays. In brief, the daily observation of the corona is dependent upon the practical registration of images formed by the heat rays alone.

In 1895, Mr. Hale, adopting these ideas, constructed for the study of the corona a differential apparatus, consisting of two very delicate and sensitive bolometers. The apparatus measures, at a given point of the sky, the heat emitted by the corona, augmented by a considerable amount of diffuse atmospheric heat, but it has not yet given any certain result on the corona.[2]

For my part I pursued my first idea. The infra-red radiation of our sky is faint, but, on the other hand, is the infra-red radiation of the corona marked? I proposed to measure it at

[1] *Comptes Rendus*, 131, 658, 1900.

[2] Mr. Hale's experiments were made at the time of maximum Sun-spots, when the corona has the same intensity and the same extent at all points of the solar circumference. Hence, probably, the cause of failure.

he total eclipse of 1896 in Japan. I constructed for this purpose a very simple apparatus, consisting of a thermo-electric pile, which could not be used on account of the bad weather. I employed this same apparatus for the same investigation during the eclipse of May 1900, in Spain, with the aid of M. Charbonneaux, assistant astronomer (see this JOURNAL **12**, 287). The infra-red radiation near λ 1.3 μ was found to be considerable, amounting to as much as from one half to one third of the radiation of the same points in the sky after the eclipse, at an elevated station where the air, it is true, is remarkably pure and dry. This result indicates the possibility of obtaining the corona under ordinary conditions with the heat rays alone.

Upon my return I employed at Meudon, where the sky is, however, less favorable, the same apparatus and a similar apparatus for the daily study of the corona, with the constant aid of M. Charbonneaux. I now present the first results, which are of slight importance, but at least show the value of the method.

The eclipse apparatus comprised: (1) a mirror of 0.30m aperture and 1.50m focal length; (2) a slit spectroscope, with lenses and prism of crown glass; (3) a sensitive Melloni thermopile; (4) a Deprez-d'Arsonval galvanometer, not very sensitive, but dead-beat, with constant zero, simple and easily manipulated. The collimator slit was 12mm high and 1mm wide; the thermopile received only the infra-red heat from the region between λ 1 μ and λ 1.8 μ.[1]

At Meudon the Melloni thermopile has been replaced by a Rubens thermopile, and the collimator slit by a circular aperture

[1] These details aid in explaining the cause of the differences between our results and those of Mr. Abbot, who also measured the heat of the corona at the same eclipse with a very sensitive bolometer. In his apparatus the radiation passes through no glass or other absorbent and comprises all the high and low temperature rays (*tous les rayons de haute et basse température*) from 0.5 μ to 60 μ at least. Our measure, on the contrary, involved only the high temperature rays. Mr. Abbot obtained negative deflections for the center of the Moon and the inner corona, and concluded from this that the corona is colder than the bolometer. Now the corona certainly emits intense red and yellow rays, which give strong positive deflections with a sensitive bolometer. The low temperature rays, which give negative deflections, must be still more intense. (*Il faut que les rayons de basse température à déviation négative soient plus intenses encore.*)

4mm in diameter. The Sun was displaced with reference to this aperture so as to permit measurements to be made of the heat at points 3′ of arc apart on the same diameter at distances from the limb ranging from 5′ to 20′. It has been found, at all hours of the day, that the sum of the deviations measured on the solar equator is uniformly greater than the corresponding sum on the line through the poles. This characteristic difference has been ascribed to the corona, which at present is of the form peculiar to the Sun-spot minimum and is more intense at the equator than at the poles.[1]

In a second apparatus the 4 mm aperture has been replaced by an opening 1 mm in diameter, the prism has been discarded, and the beam projected directly upon the linear thermopile by means of a cylindrical lens. The thermopile received the rays lying between 0.5 μ and 2.8 μ (limit of transparency of the glass). The results in the second series of experiments have been the same as in the former case. I give here a table showing the total deviations measured in the four principal directions.

	Pole		Equator	
	North	South	East	West
September 26	21.0	22.7	26.4	24.0
September 27	23.0	21.5	25.5	27.0
October 3	22.8	21.2	27.8	27.9
October 5	22.2	21.7	28.6	28.8
October 6	23.8	22.3	27.8	28.1

As a systematic error due to the position of the receiving apparatus might be feared, this apparatus (support of the aperture, cylindrical lens, and thermopile) was turned through 90°, the aperture remaining fixed.[2] The results remain the same.

[1] It must be assumed that the diffuse heat of our atmosphere is uniformly distributed around the Sun.

[2] We have also avoided all chance of error due to a possible variation in the diffuse heat of our atmosphere by measuring several times, during the experiment, the heat emitted by a given point of the sky.

The differences detected thus seem to be really due to the corona and would be the first manifestation of the corona without an eclipse.

But these results, obtained with crude and inexpensive apparatus, are incomplete. To make further advances it would be necessary to have a more sensitive galvanometer, to provide for the rotation of the receiving apparatus about the center of the Sun in order to avoid loss of time, to measure only the infra-red heat outside of the absorption bands of water-vapor, and to attempt a photographic registration of the deflections, from which an image of the corona could be built up point by point.

However, direct photography of the images formed with the infra-red rays, which has not yet been accomplished, is alone capable of furnishing a complete solution; it would give at the same time the lower part of the solar atmosphere (chromosphere and prominences) more simply than the classic method of the spectroscope.

THE HEAT RADIATION OF THE CORONA.

By S. P. Langley.

In a preliminary account of the Smithsonian observations of the eclipse of May 28, 1900,[1] I mentioned that although previous efforts had been made to ascertain the heat of the corona, the bolometric measures then taken were probably the first which had really shown it, but the brief description given of the work perhaps did not convey to the reader the full import of the observation.

Long work upon the Moon with the bolometer by me, in former years, had led to an improvement of the instrument and developed skill in its use. At the time of the eclipse it was capable of indicating a deflection of several thousand bolometric degrees, but its sensitiveness was intentionally reduced until it gave a deflection upon the full Moon of only 85 such degrees, as is shown by measurements since the observation.

Now the inner corona is well known from visual observation to be intrinsically much brighter than the full Moon, and if its heat were proportionate to its light, it should give a deflection of at least something over a hundred bolometric degrees. It gave, however, a deflection of only five such degrees.

The reader cannot but have noted, in the great photographs obtained by the 135-foot lens loaned by Professor Pickering, the appearance of what so much resembles an electric discharge around the poles. It is by no means here shown for the first time, but perhaps never with more distinctness.

I do not mean to say that the corona is such an electric phenomenon, and not formed of incandescent matter, gaseous or solid. On this point evidence is still incomplete, yet the present observations seem to bring some additional evidence in favor of the first view, for the absence of heat is obviously

[1] *Science*, June 22, 1900.

consonant with it, and it is supported by independent studies of the glow discharge.[1]

I may add that the bolometer, however trustworthy an instrument, demands an installment in a chamber of uniform temperature, with much accessory apparatus for its best effect, and that this was provided for it on the present occasion. What is still more important, it, like any other apparatus of the kind, should be in the hands of one long familiar with it, to give reliable information at a time so brief and trying as that of totality. While I have familiarity myself in its use, yet considering that Mr. Abbot was in more continuous recent practice, I assigned the observation to him, and I have all the confidence in its results that I should have, had I made it myself.

[1] It is well known that Ångström found ("Strahlung verdünnter Gase," *Ann. der Phys. und Chem.*, 48, 493, 1893,) in 1893, that the glow discharge had no infra-red spectrum, and Wood found ("Experimental determination of temperature in Geissler tubes," *Physical Review*, 4, 191, 1896,) that the temperature of the glow discharge was only some 15 or 20 degrees Centigrade above that of the surroundings.

ON SOME ATTEMPTS TO DETECT THE SOLAR CORONA IN FULL SUNLIGHT WITH A BOLOMETER.

By GEORGE E. HALE.

DURING the last seven years I have made many attempts to detect the solar corona in full sunlight. In spite of the negative outcome of these experiments it may serve a useful purpose to summarize them here, particularly as results widely different from my own have been published by M. Deslandres.[1]

The method employed in my earlier work was a photographic one, requiring the use of a spectroheliograph adjusted for the K line. The principle of this method, and the experiments made by its aid on Pike's Peak in 1893 and on Mt. Etna in 1894 have been described elsewhere,[2] and need not be given here. Suffice it to say that no images which could reasonably be regarded as representing the corona were secured.

After Professor Riccò had completed his tests of the photographic method it was decided that little or nothing could be expected from further attempts of this kind. The possibility of sufficiently increasing the contrast between the corona and sky by the use of the dark K line or in any other known way did not appear promising, and I accordingly turned my attention toward the development of an entirely different method, based upon the use of a bolometer or some similar heat-measuring instrument.

A full description of this method was published in 1895.[3] The essential principle involved is not the use of the less refrangible rays of the spectrum, but the employment of a heat-measuring instrument giving deflections proportional to the energy received. Assuming the sky radiation at a given distance from the Sun to have the same intensity at all position

[1] See p. 366.

[2] HALE, *Astronomy and Astro-Physics*, October 1894. RICCÒ, ASTROPHYSICAL JOURNAL, 1, 18, 1895.

[3] ASTROPHYSICAL JOURNAL, 1, 318, 1895.

angles, it is evident that the sky deflection may be taken as the scale zero, and hence that the relative radiation of any two parts of the corona may be measured as readily in full sunlight as at times of total eclipse.

The instruments used in successive years are enumerated below. In all of the experiments I have had the efficient assistance of Mr. Ferdinand Ellerman.

1895. Silvered mirror of 24 cm aperture and about 2 m focal length, mounted equatorially. Platinum bolometer 4 mm long, 0.5 mm wide, mounted radially in water jacket. Both arms exposed, one to corona, the other to sky beyond corona. Rubens-Du Bois galvanometer, with light needle system. Different deflections were obtained at different position angles, but they were subsequently found to be due to instrumental causes.

1896. Silvered mirror of 60 cm aperture and 18.6 m focal length, used with a large heliostat. Platinum bolometer 30 mm long, 4 mm wide, mounted in radial slot in heavy cast-iron drum, surrounded by water jacket, with central hole through which rays forming 17.5 cm solar image passed freely. Both arms exposed, as above. Rubens-Du Bois galvanometer. Different deflections were observed at different position angles, but these were traced to the effect of rotating the bolometer, and were not considered coronal.

1898. Forty-inch refractor. Compound bolometer having in each arm 5 platinum strips 35 mm long and 0.8 mm wide, in water jacket. Bolometer arms radial, centers equidistant from center of Sun and 22 mm apart, both exposed to corona. Rubens-Du Bois galvanometer. In this case my hope was to detect the edge of a coronal streamer as the bolometer passed over it. The deflections should occur in pairs, a positive deflection being followed by a negative one. No results that could be surely attributed to the corona were obtained.

1899. Laboratory experiments with the bolometer used in 1898 showed that a faint artificial corona could be detected as easily when projected upon a very bright background as when observed alone.

1900. The apparatus used at the total solar eclipse of May 28 consisted of a silvered mirror of 50cm aperture and 8.1m focal length, used in conjunction with a coelostat; and a platinum bolometer 10mm long, 1mm wide, in water-jacket, one arm exposed. The bolometer remained at rest, and the radiation from a radial strip at any position angle in the corona could be brought on to the bolometer by the aid of a rotating drum, containing a suitable combination of mirrors. The galvanometer was an exceedingly sensitive one made by Dr. Mendenhall. As has been previously stated,[1] no measures were obtained during the total phase, but just after totality no difference could be detected between the radiation of the Moon and that of the corona.

The following conclusions may be drawn from the observations made during the course of this investigation:

1. The heat radiation of the sky near the Sun, under excellent atmospheric conditions, is many hundreds of times greater than that of the corona. As a differential method has been used in most cases, no actual measures of this radiation can be given, but the above statement, based on deflections observed when balancing with a shunted galvanometer, may be regarded as a very conservative one.[2]

2. The heat radiation of the corona is very small—much less in proportion to its light than that of the full Moon. The best evidence I obtained of this was during the partial phase of the eclipse, when no difference was detected between the radiation of the dark Moon and that of the corona.

3. The small intensity of the coronal heat, as measured by Mr. Abbot during the recent eclipse, fully accounts for the

[1] ASTROPHYSICAL JOURNAL, 12, 88, 1900.

[2] A *maximum* value of the ratio of the coronal heat to that of the sky, deduced from Mr. Abbot's measures before and during totality, is about $\frac{1}{1100}$. The measure of the sky radiation here employed was made about five minutes before second contact, and is certainly much less than what would have been recorded in full sunlight.

I am unable to understand M. Deslandres' explanation of this result as due to "negative-deflection-giving rays." If the corona emits rays which have the power of annulling the heating effect of ordinary radiations, why does M. Deslandres obtain the same results with and without a prism?

failure of my attempts to detect the corona in full sunlight. In spite of the extreme sensitiveness of my instruments, they were not capable of detecting the minute difference between corona and sky.

4. On account of the uniformity of the sky radiation under good atmospheric conditions, and the success of the experiments made with an artificial corona, it appears probable that the method will ultimately give a means of determining at least the approximate form of the corona in full sunlight.

5. This method should not be confused with M. Deslandres' plan of photographing the corona by the exclusive use of the infra-red rays, as the essential principle is entirely different in the two cases.

The work is being continued at the Yerkes Observatory with the aid of the extremely sensitive radiometer recently used here by Professor Nichols in his researches on the heat radiation of stars and planets.

YERKES OBSERVATORY,
December, 1900.

REMARKS ON MR. EASTON'S ARTICLE "ON A NEW THEORY OF THE MILKY WAY" IN THE *ASTROPHYSICAL JOURNAL* FOR SEPTEMBER.

By H. SEELIGER.

IN my paper entitled "Considerations on the Distribution of the Fixed Stars in Space,"[1] I have called attention to a fallacy which has been employed in the explanation of the surprising accumulation of stars in certain regions of the Milky Way in the immediate neighborhood of regions very deficient in stars, or in the explanation of the other fact that quite starless regions occur within portions of the Milky Way which are pretty uniformly occupied by stars. As many of the readers of this JOURNAL will perhaps not see this paper, I take the liberty of repeating here the part referred to, quoting literally the main point at issue: "No reasons of a general nature can be assigned why an annular arrangement of the accumulations in the Milky Way is *a priori* any more probable than any other distribution. This has to be especially mentioned because the opinion has been expressed by others that the occurrence of bright and hence dense accumulations, in the immediate neighborhood of starless or empty regions, indicates with a great degree of probability that these accumulations must have a relatively small extent in the line of sight, because otherwise we should have to assume that there were cylindrical vistas which were all turned toward the Sun in a most improbable manner. This argument is, however, based upon an error, for it can readily be seen that with a given number of stars the probability for any given apparent distribution, and hence for the occurrence of certain definite vistas, is entirely independent of the dimensions of space in the line of sight. A few words will now be given to this subject in order to dispel any lack of

[1] "Betrachtungen über die raümliche Vertheilung der Fixsterne," *Abhandlungen der bayer. Akademie der Wissenschaft*, München, 1898, p. 628.

clearness on this really important point. Let N be the number of those stars of the Milky Way which appear to be within a large area of the heavens $d\Omega$, and which therefore are actually situated within a conical space R, the vertex of which is at the observer. If $d\omega$ is a small portion of the sky lying within $d\Omega$, and K is the conical space corresponding to it, then the probability that, with an accidental distribution of the stars, just n of the N stars will appear to lie within $d\omega$ will be

$$W_n = \frac{N \cdot N-1 \ldots N-n+1}{1 \cdot 2 \ldots n} \left(\frac{K}{R}\right)^n \left(1-\frac{K}{R}\right)^{N-n} \ldots\ldots . \quad (1)$$

This formula is the more exact the smaller the total volume of the stars in comparison to the volumes of space coming into consideration. In view of the exceedingly sparse distribution of the cosmical masses in space, it may therefore be considered as almost absolutely correct. In order to direct our attention to the general case, R may consist of a series of frusta of cones which are bounded by spheres with the radii r_0 and r_0', r_1 and r_1', etc., and with the center at the observer.

Then

$$R = \frac{d\Omega}{3}\left[(r'_0{}^3 - r_0^3) + (r'_1{}^3 - r_1^3) + \ldots .\right].$$

$$K = \frac{d\omega}{3}\left[(r'_0{}^3 - r_0^3) + (r'_1{}^3 - r_1^3) + \ldots .\right].$$

and $\frac{K}{R} = \frac{d\omega}{d\Omega}$ is, like W_n, *entirely independent* of the dimensions in the line of sight. It is a matter of complete indifference in the question of probability whether the *same* number of stars is spread out in the direction of the line of sight or is compressed into a small space."

I had thought that this discussion had made this very simple matter entirely clear. I was therefore not a little surprised to learn that Mr. Easton had raised objections to it (*loc. cit.*, p. 150). A quarrel as to the correctness or incorrectness of such simple mathematical considerations is obviously entirely impossible, and I only regret that I have to refer to this here. Nevertheless, after this experience it seems to me that a few other remarks may be in order.

I first beg to state that my mode of presentation is *not* drawn from J. Herschel. The citation from the "Outlines" made by Mr. Easton was hitherto entirely unknown to me. This citation, however, can prove nothing else than that Herschel also was a victim of the same serious blunder as many other astronomers after him. It is very interesting psychologically and invites further inquiries as to how it is possible that so simple a blunder could be made by different individuals quite independently of each other. It would appear to me that in this case an incorrect appreciation of the principles of probabilities is associated with the adoption of certain preconceived opinions as to the correctness of which a decision is impossible in advance.

If we know nothing as to the manner of the origin of a given constellation of stars in the heavens, which is actually the case, we may, on the assumption that this constellation originated by accident, keep within the limits of our knowledge, and hence apply the principles of probabilities, that is, we may speak of the probability of the constellations coming into existence.

If we now arrange a given number of stars in constellations, each arrangement is as probable as any other. It is therefore equally probable that these stars lie within an accurate circle or polygon, or in any more complex or irregular curve.

It is well known how much persons with an incomplete mathematical education are accustomed to object to this consequence of the elementary principles of probabilities, although probably no one would dare to doubt its correctness.

A correct application of this principle is obtained even in complicated cases by the laws of probabilities, which, in the case mentioned above, lead to the universally known formula (1). In this formula there only appears the quotient $\frac{K}{R} = \frac{d\omega}{d\Omega}$, whence follows the indisputable theorem that W_n is entirely independent of whether the N stars are distributed according to the laws of chance in a space of great or small extent in the line of sight. But, on the other hand, the expression (1) shows

W_n is in a high degree dependent upon n. We know that for a small value of n, W_n is relatively small, and with increasing n at first increases very rapidly, then more slowly until at about $n = N\frac{K}{R}$ it reaches a maximum, and from there it decreases, at first slowly and afterwards more rapidly. It also follows that the occurrence in the Milky Way of dark places in the midst of stellar accumulations is indeed very improbable, but in every case *the probability remains just as slight if we compress the same number of stars into a smaller space*, if this covers the same portion of the heavens as before. If anyone questions this result, he questions the fundamental principles of probabilities and commits a blunder, since we are here concerned with such exceedingly simple considerations. The most trivial illustrations can be cited in which similar relations occur.

If a great number of trees are planted in a ring-shaped area, and if we may assume that they were distributed at random, then the probability of the occurrence of cylindrical vistas — for an observer at the center of the circle, is entirely independent of whether the same number of trees stand in a broad ring or are compressed into a narrower ring. This is true as long as the trees are not too thick in comparison to the dimensions of the space at disposal.

The condition of things is changed, however, if we wonder at the actual occurrence of such very improbable irregular distribution of stars in the sphere, and seek for causes which might reduce this improbability. But the problem in probabilities proposed above, and treated by me, has nothing whatever to do with this question. It is possible that dynamical, physical, or other points of view, may lead to the understanding that a pronounced compression of the stars in space may favor the development of bright and dark places in the Milky Way; indeed, I cannot deny that such a suspicion is natural. But this is not discussed either by J. Herschel or by Easton; indeed, such assumptions seem to have unconsciously crept in as preconceived opinions, as I have already suggested above. If particular

reference had been made to this possibility, the criticism of an error in logic would not have applied, but in the present state of our knowledge only unproven and easily assailable suspicions could be expressed. If it should become possible to avoid the latter, this would signify an important step in the progress of stellar astronomy.

MUNICH,
October 15, 1900.

Minor Contributions and Notes

APPOINTMENT OF PROFESSOR W. W. CAMPBELL AS DIRECTOR OF THE LICK OBSERVATORY.

At a meeting of the Board of Regents of the University of California, held on December 11, the previous action of the Observatory Committee in appointing Professor W. W. Campbell as Director of the Lick Observatory was approved by unanimous vote. The wisdom of this choice will be apparent to everyone familiar with the circumstances of the case. The task which falls to the successor of Professor Keeler is no easy one, a fact which the Observatory Committee fully appreciated. They accordingly deferred action until the opinions of many eminent astronomers in this country and abroad could be secured. The replies, almost without exception, named Professor Campbell as first choice. It is evident that his remarkable success as an investigator, his tireless energy, and his ability to direct the works of others are widely known and appreciated. It is a pleasure to extend congratulations to the President and Regents of the University of California for the wise manner in which the appointment was made, to the Lick Observatory for its bright prospects under such leadership, and to Professor Campbell himself for the wider opportunity in the prosecution of his researches which he will now enjoy.

Striking evidence that the new Director's administration will be a progressive one is contained in the announcement which appears almost simultaneously with the news of the recent appointment. At Professor Campbell's request Mr. D. O. Mills, the donor of the Mills spectrograph, has given the sum of $24,000 to meet the expenses of an expedition to the southern hemisphere. The purpose of the expedition is to extend to the remaining naked-eye stars of the southern hemisphere Professor Campbell's well-known investigations of motions in the line of sight, the results of which have been published in this Journal. Preparations for this important work are going rapidly forward at the

Lick Observatory. It is understood that a station will be selected in Chile or Australia, and that the members of the party will remain at least two years after the instruments are ready for observations. The entire investigation, which is nearing completion for the northern stars, will involve the determination of the velocity in the line of sight of all stars down to the fifth magnitude.

G. E. H.

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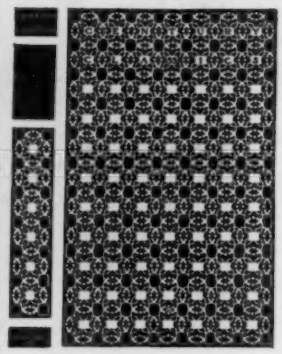

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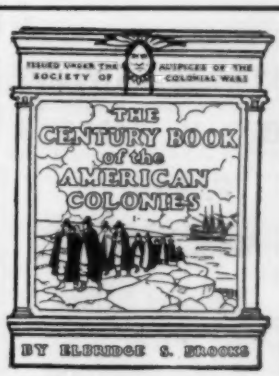
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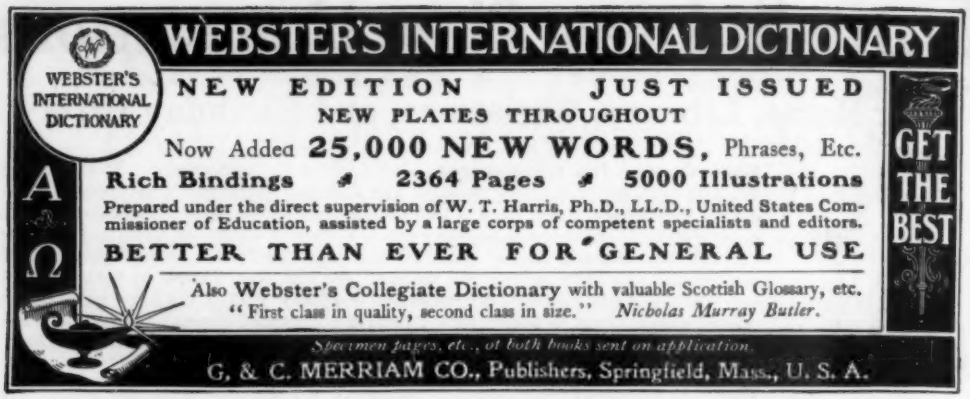
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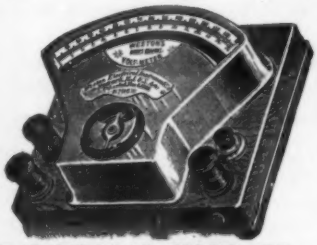

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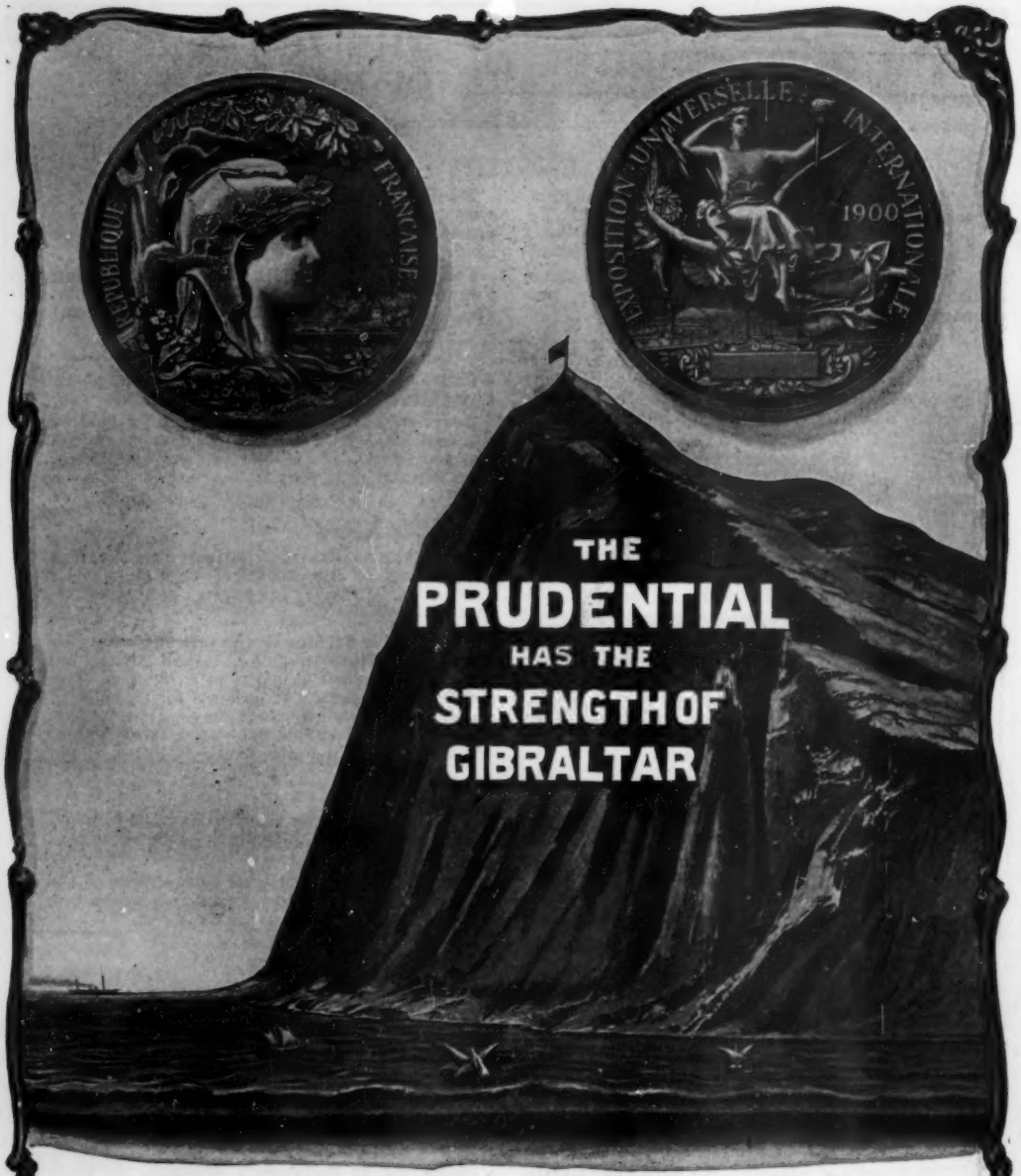

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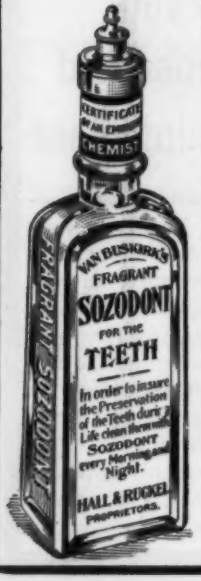

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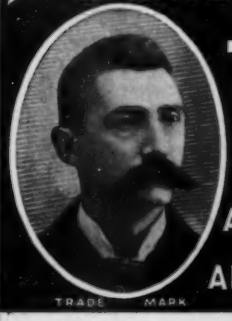

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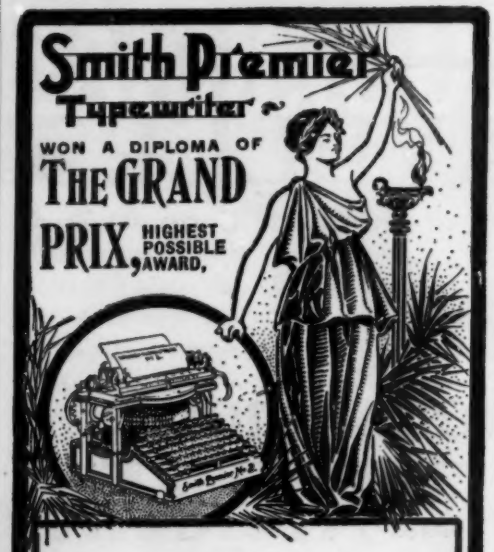

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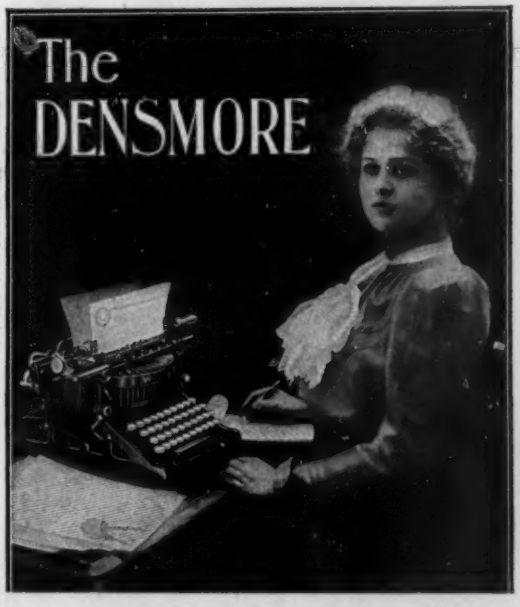

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